

National Aeronautics and Space Administration



NASA-DoD Lead-Free Electronics Project

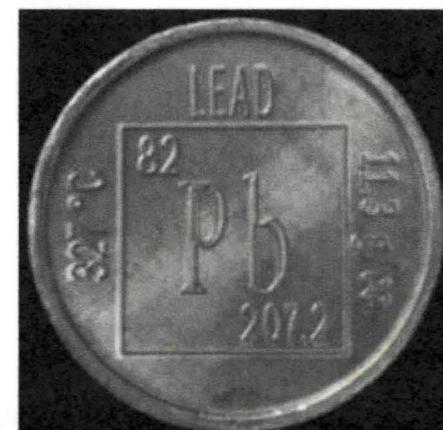
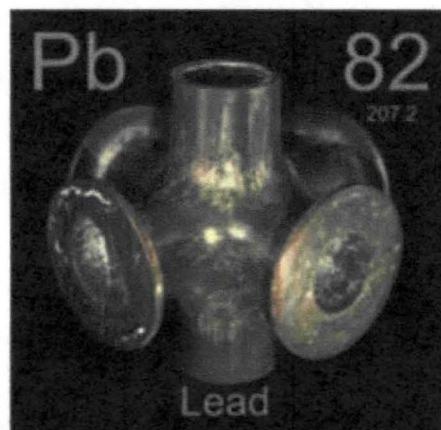
Pb-free Electronics Risk Management
(PERM) Consortium

September 27, 2011



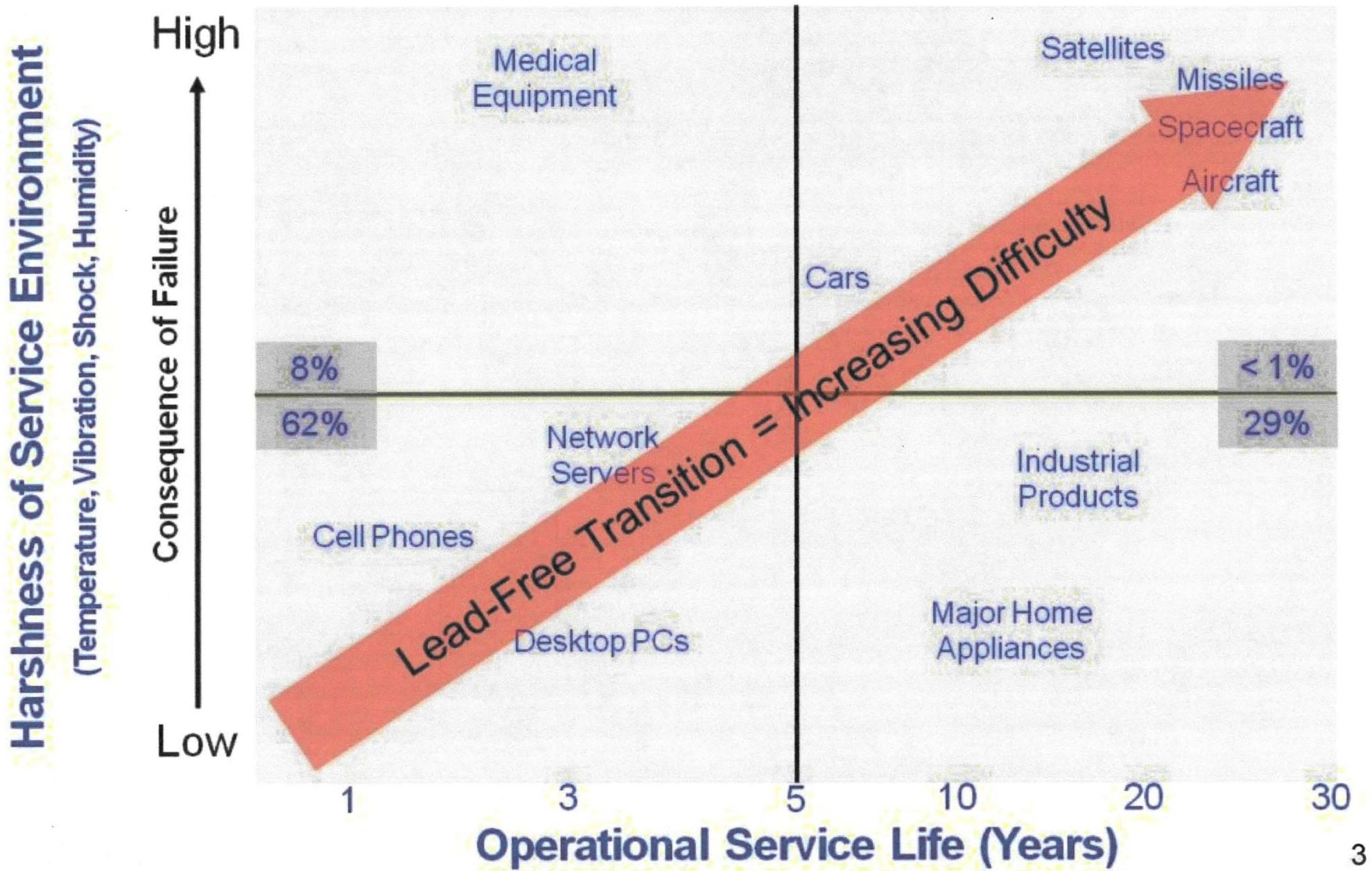
Why Lead-Free Electronics?

- Restriction and elimination of lead (Pb) in electronics products enacted by the European Union
 - ❑ Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment; Waste from Electrical and Electronic Equipment (WEEE)] and Pacific-Rim geographical regions (circa 2006).
- Non-U.S. countries continue restricting the disposal of electronic products containing Pb.
- The U.S. does not have existing federal legislation, but several states have adopted laws restricting Pb content in the manufacturing and disposal of electronic equipment.
- Aerospace and Defense OEMs are at risk because their collective demand for electronics is low compared to that of commercial manufacturers.

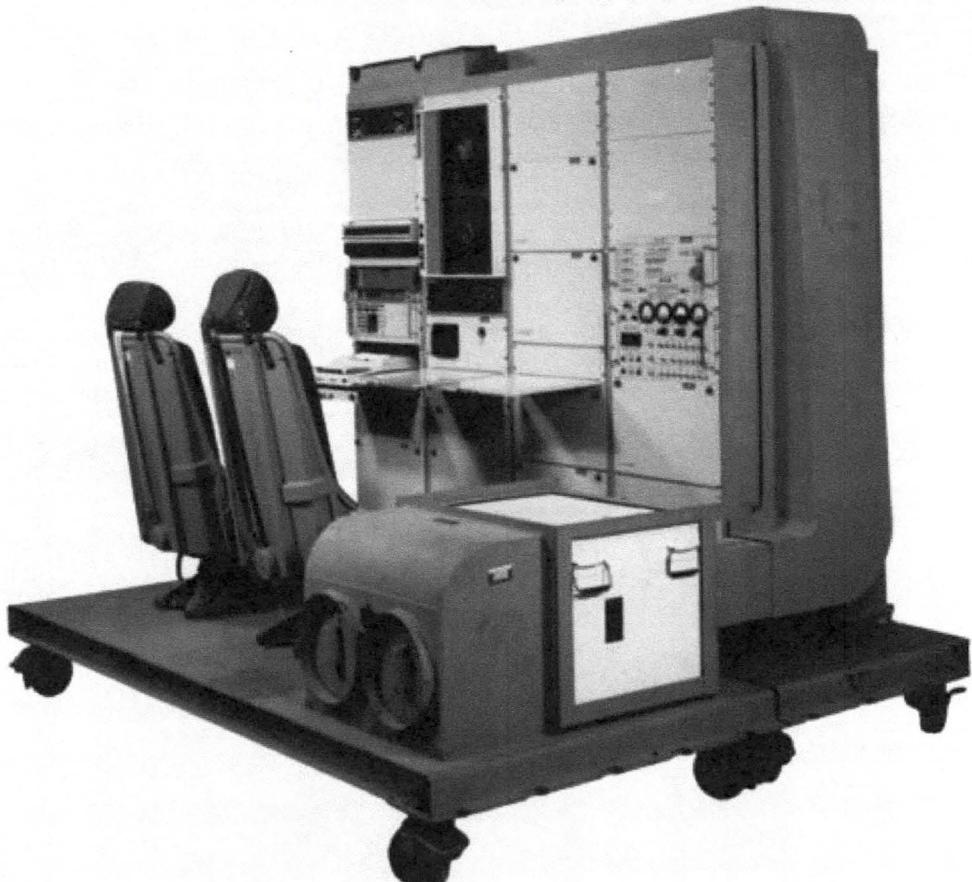




Military and Aerospace sectors have little influence on the global transition to Lead-Free (<1% Market Share)



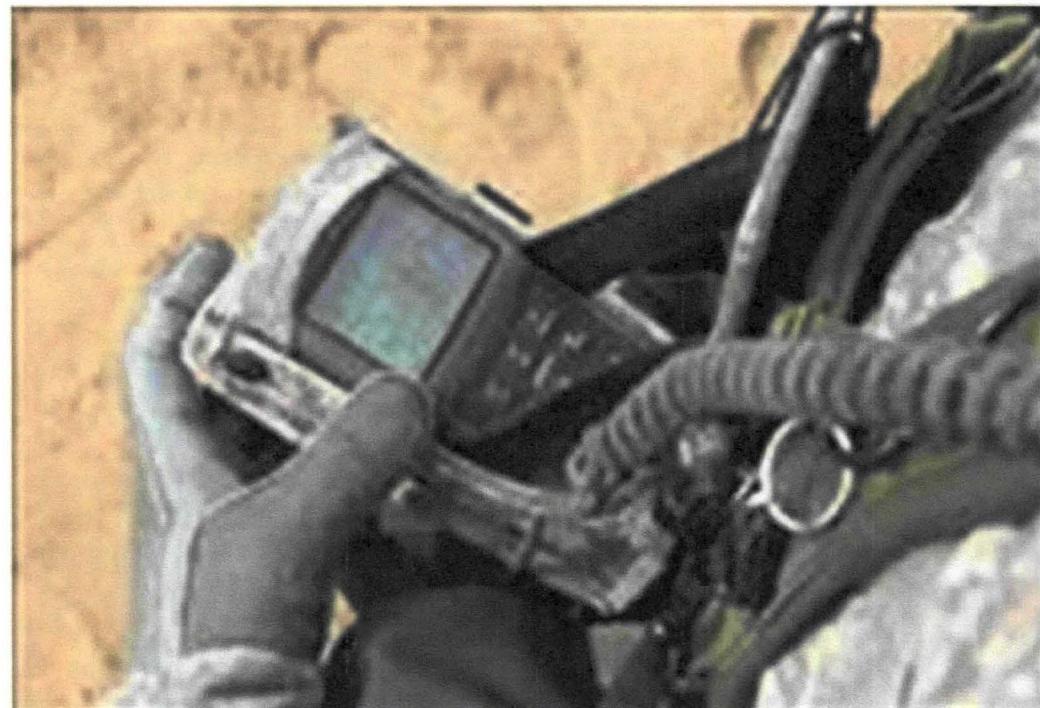
Processes Must Evolve with Technology Changes



GPS Technology Evolution

GPS in 1976 – Hundreds of pounds

GPS in 2009 – One pound





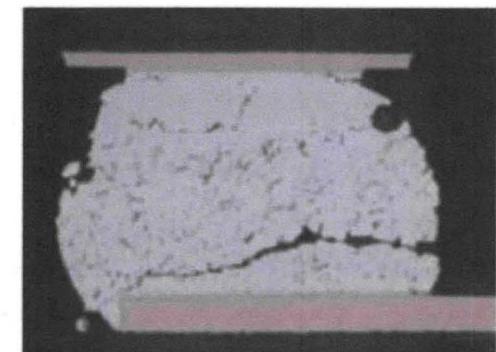
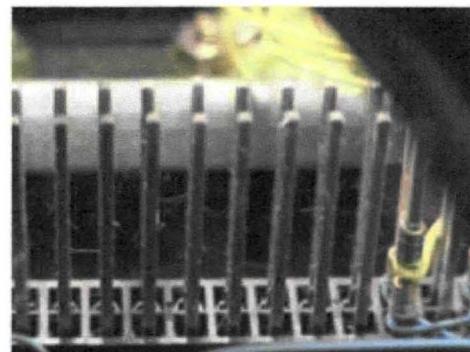
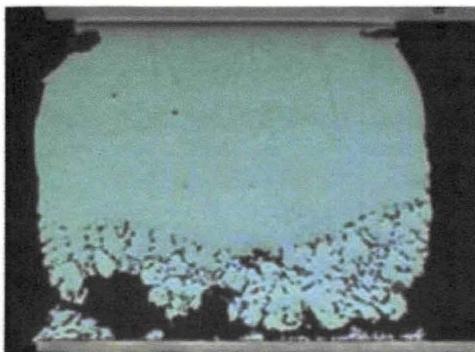
Need

Introduction of lead-free components presents one of the greatest risks to the reliability of military and aerospace electronics.

Customers, suppliers, and maintainers of aerospace and military electronic systems now have a host of concerns such as:

- Electrical shorting due to **tin whiskers**
- Incompatibility of lead-free processes and parameters (including **higher** melting points of lead-free alloys)
- **Unknown** properties that can reduce solder joint reliability

It will be critical to **fully understand the implications of reworking lead-free assemblies.**

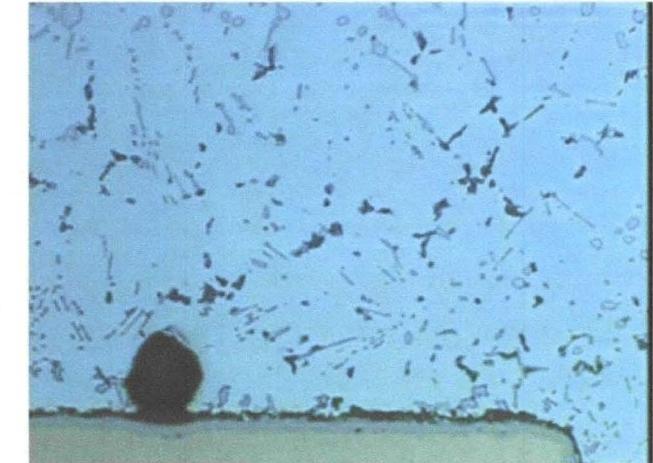
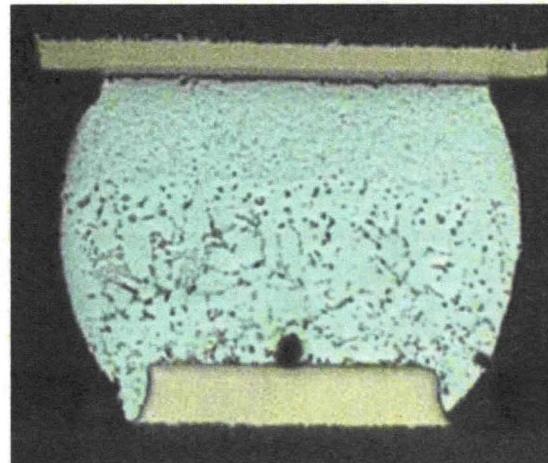
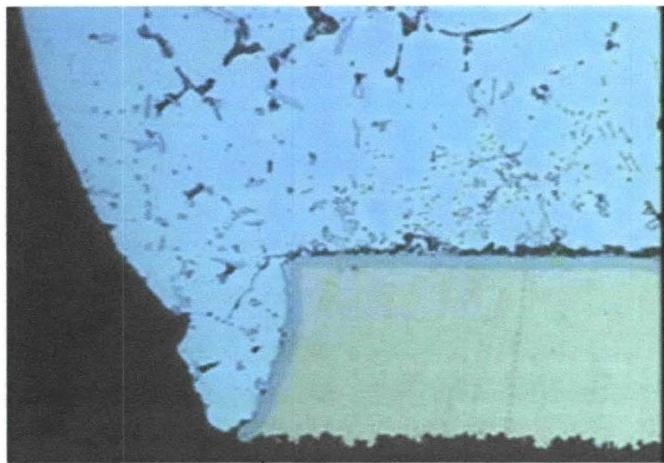




Benefit

One of the largest most comprehensive projects evaluating the reliability of lead-free solder alloys that:

- Focuses on **rework** of tin-lead and lead-free solder alloys
- Includes **mixing** of tin-lead/lead-free & lead-free/tin-lead solder alloys during **manufacturing** and **rework**.
- Furthers understanding of how lead-free solder interconnects can be **designed for** and **used in high reliability** electronic assemblies.



SAC BGA assembled in a conventional SnPb solder process. Failure in temperature cycling (-55 to 125°C) occurred in less than 150 cycles. This type of defect could escape current screening practices.



Resources

Project documents, test plans, test reports and other associated information will be available on the web:

- NASA-DoD Lead-Free Electronics Project:

http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html

- Joint Test Protocol
- Project Plan
- Final Test Reports

National Aeronautics and Space Administration

**Technology Evaluation for Environmental
Risk Mitigation Principal Center**





Lead-Free Solder Alloys

SAC305 (Sn3.0Ag0.5Cu)

➤ Surface mount assembly



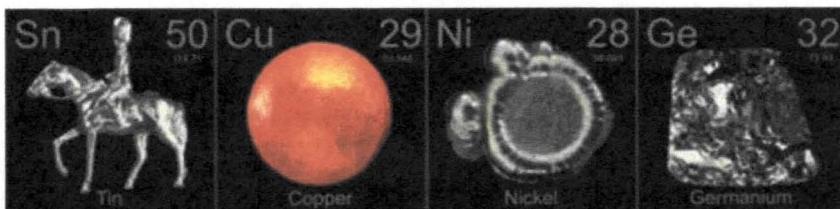
- Chosen for reflow soldering because it has shown the most promise as a primary replacement for tin-lead solder.
- Serves best as a “general purpose” alloy. {EnviroMark™ 907 from Kester.}

SN100C (Sn0.7Cu0.05Ni+Ge)

➤ Plated through hole

➤ Surface mount assembly

- This alloy is commercially available.
- Due to superior performance, industry is switching to nickel stabilized tin-copper alloy over standard tin-copper.
- Does not require special solder pots.

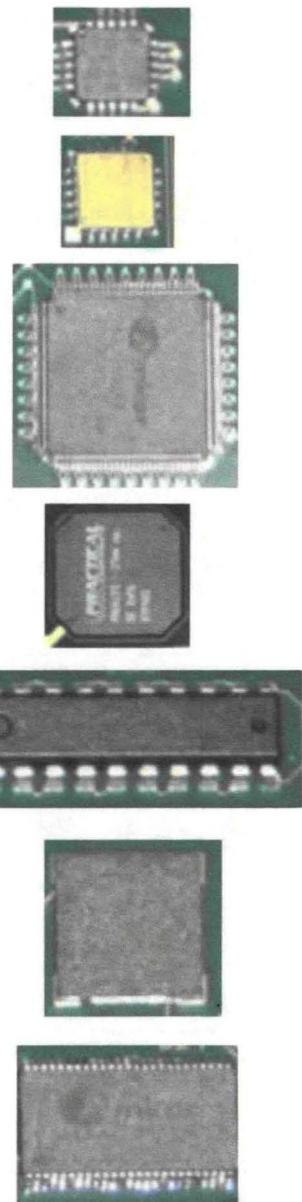


NS^e-SOLDER
LEAD FREE
LEAD FREE SOLDERING



Components

| Component Type | Component Finish | Part Number |
|----------------|------------------|------------------------------------|
| CLCC-20 | SAC305 | 20LCC-1.27mm-8.90mm-DC-L-Au |
| | SnPb | Tinning for SAC305 & SnPb |
| QFN-20 | Sn | A-MLF20-5mm-.65mm-DC |
| | SnPb | |
| TQFP-144 | Sn | |
| | SnPb | A-TQFP144-20mm-.5mm-2.0-DC |
| | NiPdAu | Tinning for SAC305 & SnPb |
| | SAC305 | |
| BGA-225 | SnPb | |
| | SAC405 | PBGA225-1.5mm-27mm-DC |
| PDIP-20 | Sn | |
| | NiPdAu | A-PDIP20T-7.6mm-DC |
| | SnPb | |
| CSP-100 | SnPb | |
| | SAC105 | A-CABGA100-.8mm-10mm-DC |
| | SN100C | Reballled for SN100C |
| TSOP-50 | Sn | |
| | SnBi | A-TII-TSOP50-10.16x20.95mm-.8mm-DC |
| | SnPb | |



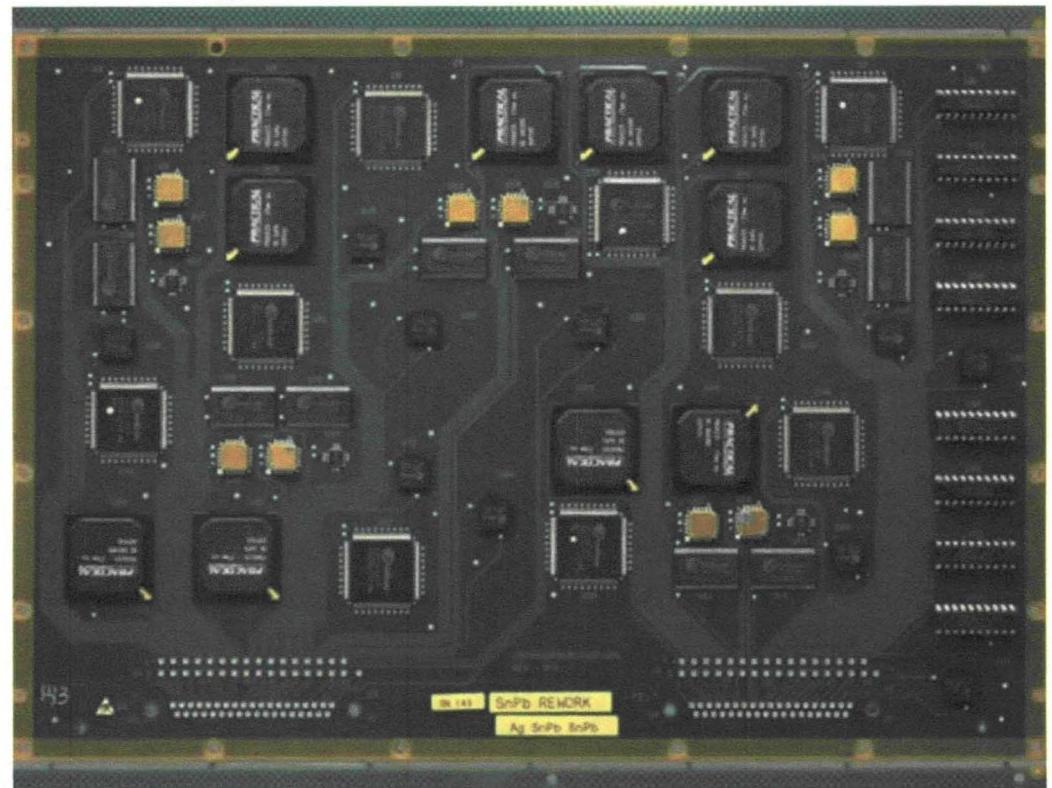
Components not to scale



Test Vehicles

Assembled by BAE Systems - Irving, Texas

- 120 = “Manufactured”
- 73 = “Rework”
 - 14.5”X 9”X 0.09”
 - 6 layers of 0.5 ounce copper
 - FR4 per IPC-4101/26 with a minimum Tg of 170°C
(Isola 370HR)
 - Surface Finish
 - Most Immersion Ag
 - Some ENIG

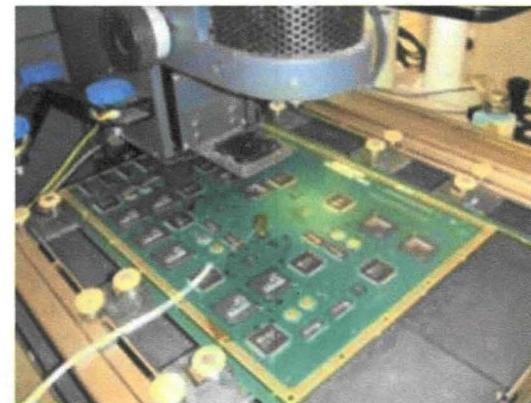




Test Vehicles

Assembly Details - SnPb

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SnPb
 - Preheat = ~ 120 seconds @140-183°C
 - Solder joint peak temperature = 225°C
 - Time above reflow = 60-90 sec
 - Ramp Rate = 2-3 °C/sec
- Wave Soldering
- Location – BAE Systems Irving, Texas
- Wave Profile = SnPb
 - Solder Pot Temperature = 250°C
 - Preheat Board T = 101°C
 - Peak Temperature = 144°C
 - Speed: 110 cm/min



Assembly Details – Lead-Free

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SAC305
 - Preheat = 60-120 seconds @150-190°C
 - Peak temperature target = 243°C
 - Reflow:~20 seconds above 230°C
 - ~30-90 seconds above 220°C
- Wave Soldering
- Location – Scorpio Solutions
- Wave Profile = SN100C
 - Solder Pot Temperature = 265°C
 - Preheat Board T = 134°C
 - Peak Temperature = 155°C to 175°C
 - Speed: 90 cm/min



Test Vehicles

| Batch | Test Vehicle Type | Reflow Solder | Wave Solder |
|-------|---|---------------|-------------|
| A | Lead-Free Rework All Test Vehicles | SAC305 | SN100C |
| B | SnPb Rework* All Test Vehicles | SnPb* | SnPb* |
| C | SnPb Manufactured Test Vehicles | | |
| D | Thermal Cycle and Combined Environments | SnPb | SnPb |
| E | SnPb Manufactured Test Vehicles | | |
| F | Vibration, Mechanical Shock and Drop | SnPb | SnPb |
| G | Lead-Free Manufactured Test Vehicles | | |
| H | Thermal Cycle and Combined Environments | SAC305 | SN100C |
| I | Lead-Free Manufactured Test Vehicles | | |
| | Crane Rework Effort | SN100C | SN100C |

* NOTE: Lead-Free profiles will be used for reflow and wave soldering

Component finishes vary {SnPb & lead-free} across all test vehicle types, creating a multitude of solder alloy combinations

For this project:

- Forward Compatibility is a SnPb component attached to a printed wiring assembly using Pb-free solder with a Pb-free profile.
- Backward compatibility is a Pb-free component attached to a printed wiring assembly using SnPb solder with a SnPb solder profile.



Test Vehicles

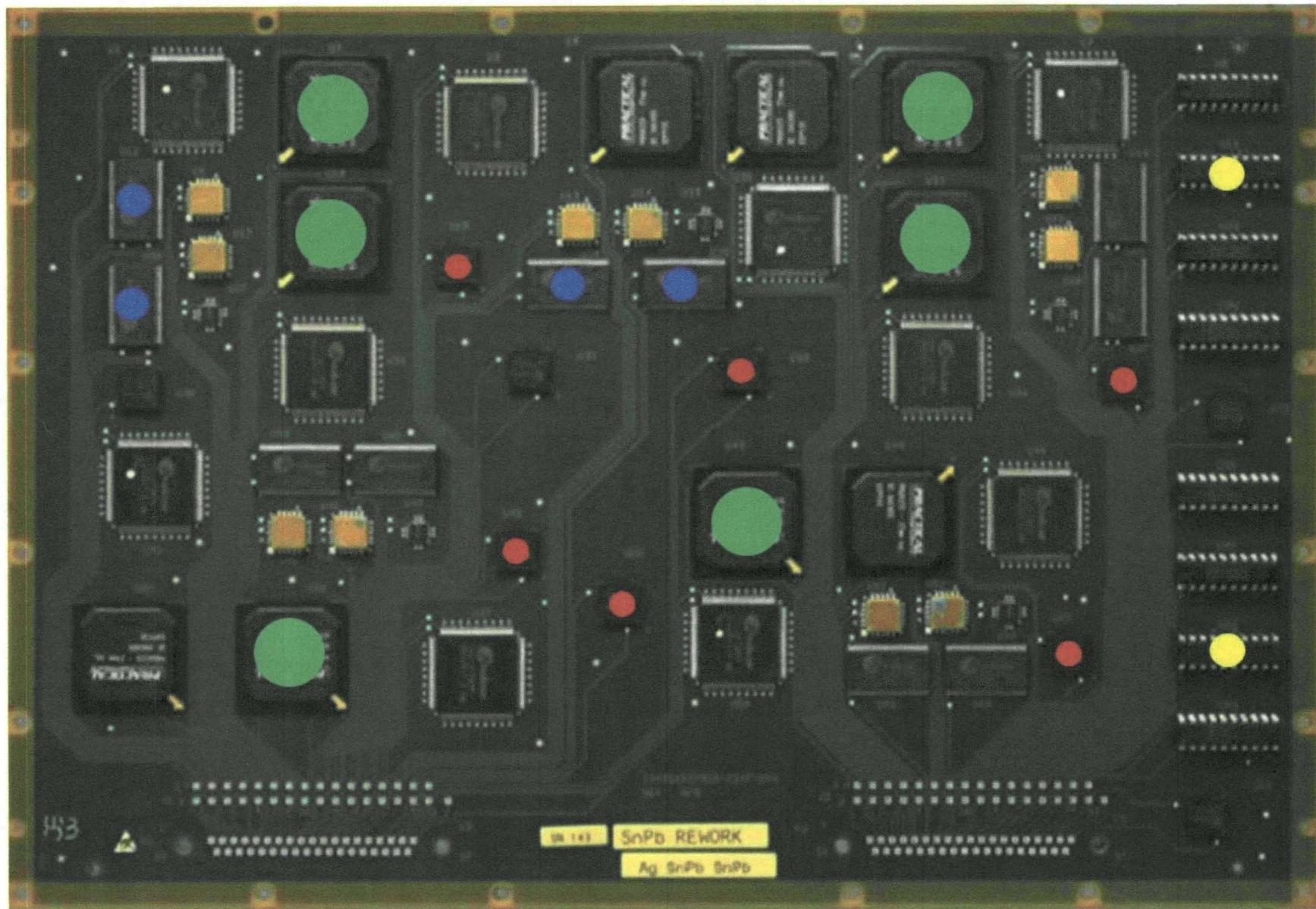
Solder alloy combinations generated during initial assembly

Component Finish

| | SAC405 | SAC305 | SAC305 Dip | SAC105 | SN100C | NiPdAu | SnBi | Sn | Matte Sn | SnPb | SnPb Dip |
|--------------|--------|--------|---------------|--------|--------|--------|--------------|------|--------------|-----------------------------------|---|
| Solder Alloy | SAC305 | BGA | CLCC | TQFP | CSP | TQFP | TSOP | TSOP | QFN TQFP | BGA CLCC CSP QFN TSOP | TQFP |
| | SN100C | BGA | CLCC | | CSP | CSP | PDIP | TSOP | PDIP TSOP | QFN TQFP | BGA CLCC CSP TSOP |
| | SnPb | BGA | CLCC | | CSP | | PDIP TQFP | TSOP | PDIP TSOP | QFN TQFP | BGA CLCC CSP PDIP QFN TSOP |



“Rework” Test Vehicles



Reworked Components

U18 – BGA-225

U43 – BGA-225

U06 – BGA-225

U02 – BGA-225

U21 – BGA-225

U56 – BGA-225

U33 – CSP-100

U50 – CSP-100

U19 – CSP-100

U37 – CSP-100

U42 – CSP-100

U60 – CSP-100

U11 – PDIP-20

U51 – PDIP-20

U12 – TSOP-50

U25 – TSOP-50

U24 – TSOP-50

U26 – TSOP-50

Component Finish/Solder Combinations

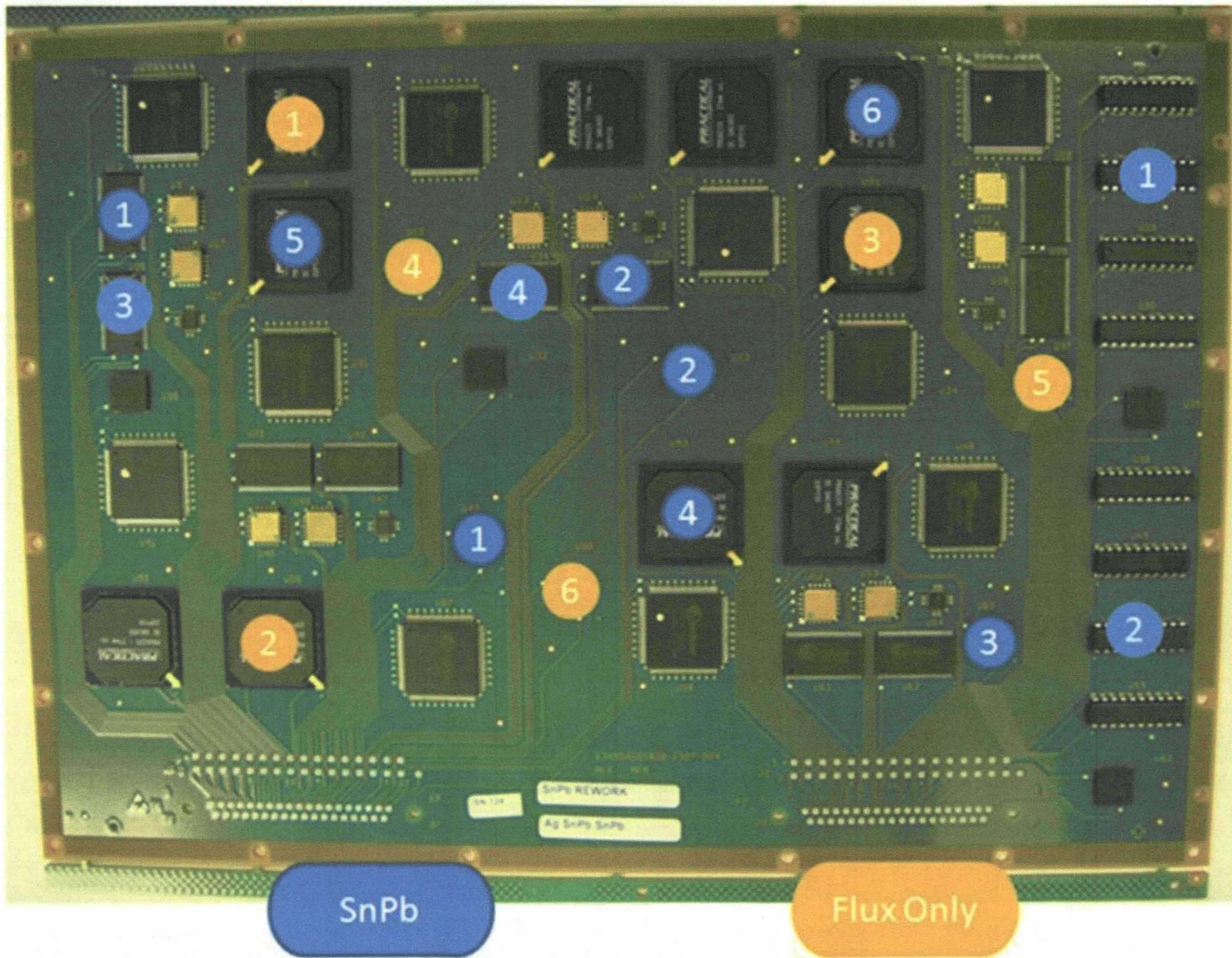
SnPb Rework



Lead-Free components introduced into a SnPb assembly

| RefDes | Component | Original Component Finish | Reflow Solder | Wave Soldedr | New Component Finish | Rework Solder |
|--------|-----------|---------------------------|---------------|--------------|----------------------|---------------|
| U18 | BGA-225 | SnPb | SnPb | | SAC405 | SnPb |
| U43 | BGA-225 | SnPb | SnPb | | SAC405 | SnPb |
| U06 | BGA-225 | SnPb | SnPb | | SAC405 | SnPb |
| U02 | BGA-225 | SnPb | SnPb | | SnPb | Flux Only |
| U21 | BGA-225 | SnPb | SnPb | | SnPb | Flux Only |
| U56 | BGA-225 | SnPb | SnPb | | SnPb | Flux Only |
| U33 | CSP-100 | SnPb | SnPb | | SAC105 | SnPb |
| U50 | CSP-100 | SnPb | SnPb | | SnPb | Flux Only |
| U19 | CSP-100 | SnPb | SnPb | | SnPb | Flux Only |
| U37 | CSP-100 | SnPb | SnPb | | SnPb | Flux Only |
| U42 | CSP-100 | SnPb | SnPb | | SAC105 | SnPb |
| U60 | CSP-100 | SnPb | SnPb | | SAC105 | SnPb |
| U11 | PDIP-20 | SnPb | | SnPb | Sn | SnPb |
| U51 | PDIP-20 | SnPb | | SnPb | Sn | SnPb |
| U12 | TSOP-50 | SnPb | SnPb | | SnPb | SnPb |
| U25 | TSOP-50 | SnPb | SnPb | | SnPb | SnPb |
| U24 | TSOP-50 | SnPb | SnPb | | Sn | SnPb |
| U26 | TSOP-50 | SnPb | SnPb | | Sn | SnPb |

Rework Procedure – SnPb Rework



Component Finish/Solder Combinations

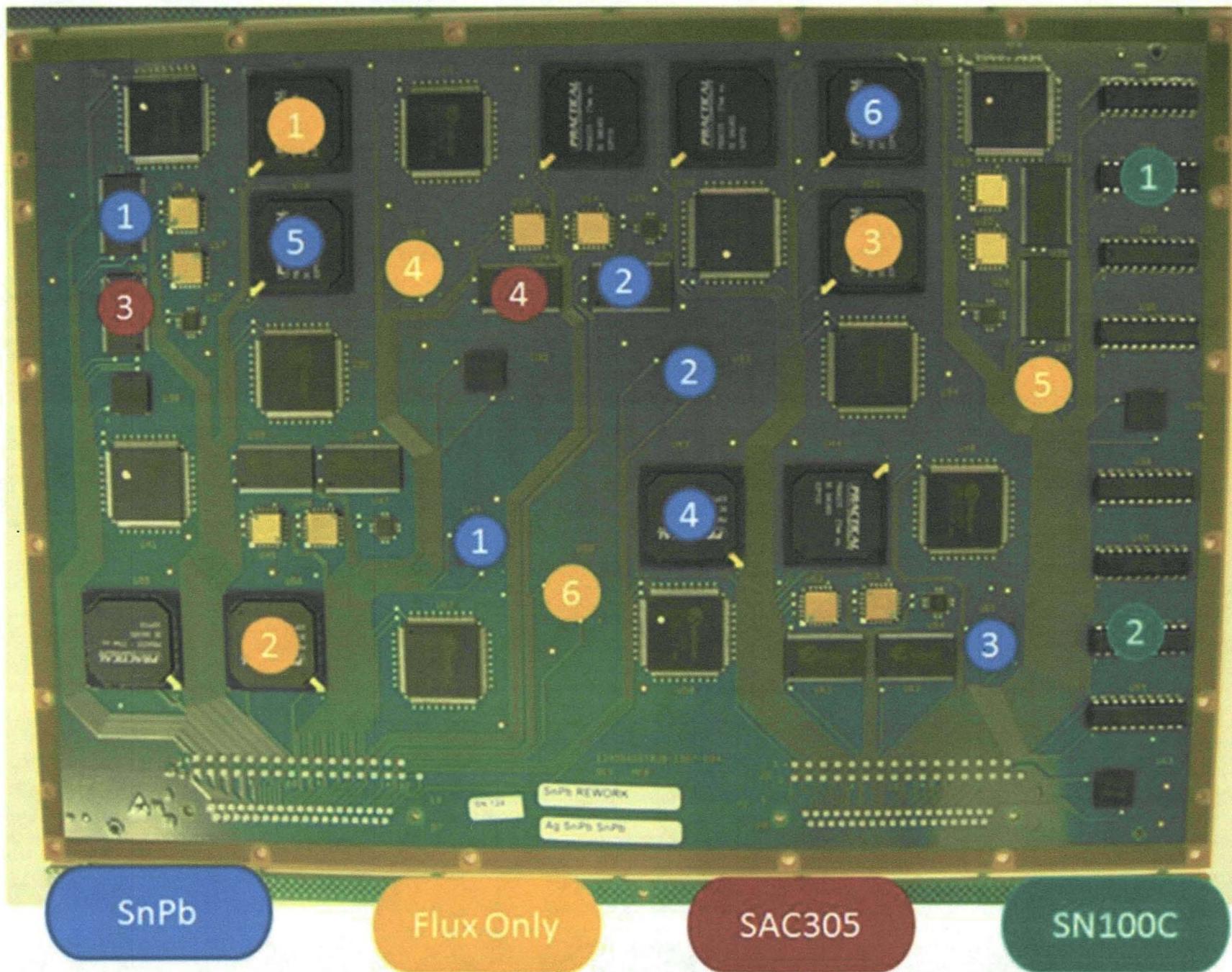
Lead-Free Rework



SnPb solder introduced into a lead-free assembly

| RefDes | Component | Original Component Finish | Reflow Solder | Wave Solder | New Component Finish | Rework Solder |
|--------|-----------|---------------------------|---------------|-------------|----------------------|---------------|
| U18 | BGA-225 | SAC405 | SAC305 | | SAC405 | SnPb |
| U43 | BGA-225 | SAC405 | SAC305 | | SAC405 | SnPb |
| U06 | BGA-225 | SAC405 | SAC305 | | SAC405 | SnPb |
| U02 | BGA-225 | SAC405 | SAC305 | | SAC405 | Flux Only |
| U21 | BGA-225 | SAC405 | SAC305 | | SAC405 | Flux Only |
| U56 | BGA-225 | SAC405 | SAC305 | | SAC405 | Flux Only |
| U33 | CSP-100 | SAC105 | SAC305 | | SAC105 | SnPb |
| U50 | CSP-100 | SAC105 | SAC305 | | SAC105 | Flux Only |
| U19 | CSP-100 | SAC105 | SAC305 | | SAC105 | Flux Only |
| U37 | CSP-100 | SAC105 | SAC305 | | SAC105 | Flux Only |
| U42 | CSP-100 | SAC105 | SAC305 | | SAC105 | SnPb |
| U60 | CSP-100 | SAC105 | SAC305 | | SAC105 | SnPb |
| U11 | PDIP-20 | Sn | | SN100C | Sn | SN100C |
| U51 | PDIP-20 | Sn | | SN100C | Sn | SN100C |
| U12 | TSOP-50 | Sn | SAC305 | | Sn | SnPb |
| U25 | TSOP-50 | Sn | SAC305 | | Sn | SnPb |
| U24 | TSOP-50 | SnBi | SAC305 | | SnBi | SAC305 |
| U26 | TSOP-50 | SnBi | SAC305 | | SnBi | SAC305 |

Rework Procedure – Lead-Free Rework





NAVSEA Crane Rework Effort

Built 30 test vehicles (sub-set of the 193 assembled)

- Test vehicles were built with **Lead-Free solder and Lead-Free component finishes only** = similar to Manufactured test vehicles for Mechanical Shock, Vibration and Drop Testing
- Lead-Free alloys, SAC305 and SN100C
- Rework was done using **only SnPb solder**
- Performed multiple pass rework 1 to 2 times on random lead-free DIP, TQFP-144, TSOP-50, LCC and QFN components
- Represents real world scenario for deployed Navy vessels
- Testing

- Thermal Cycling
-55°C to +125°C

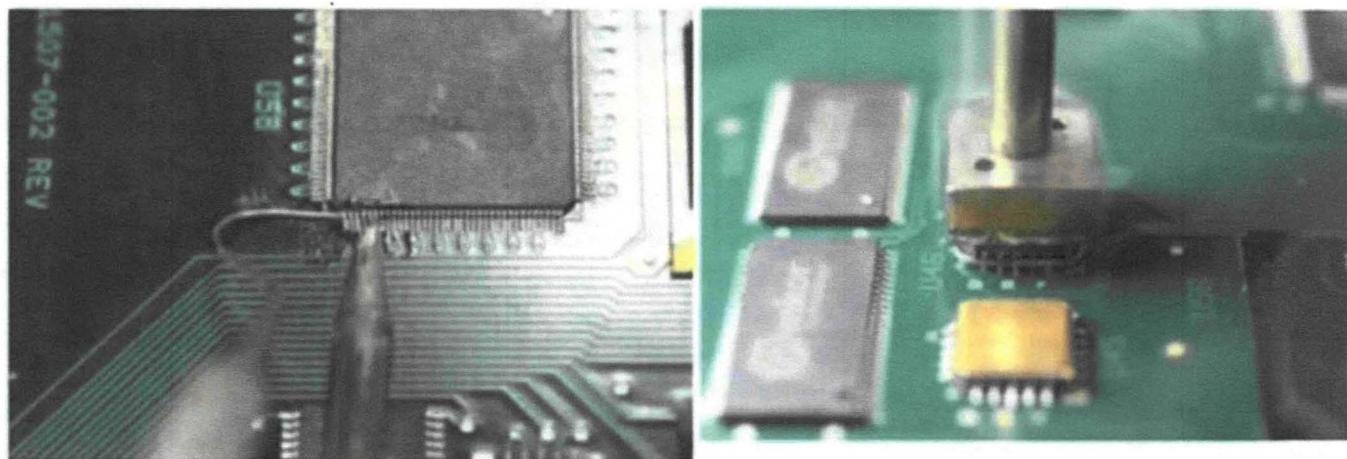
*Rockwell
Collins*

- Vibration Testing

 CELESTICA

- Drop Testing

 CELESTICA





Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
- Combined Environments Testing  **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C)  **Rockwell
Collins**
- Vibration Testing   **CELESTICA**
- Mechanical Shock Testing  **BOEING®**



Thermal Cycling -20° / 80°C

- 5 to 10°C/minute ramp
- 30 minute dwell at 80°C
- 10 minute dwell at -20°C
- Completed about 13,100 cycles





Thermal Cycling -20° / 80°C

- Approximately 13,100 cycles have been completed.
- Data is following the same trends observed in the JCAA/JGPP LFS Project
- Hopefully the thermal chamber will be allowed to operate until at least 17,000 thermal cycles have been completed.

JCAA/JGPP LFS Project -

Under the conditions of this test, Sn3.9Ag0.6Cu (SAC) and Sn3.4Ag1.0Cu3.3Bi (SACB) were always more reliable than eutectic SnPb regardless of component type (CLCC, TSOP, BGA or TQFP)

| Component | Solder/Finish | 1st Failure | N10 | N63 |
|-----------|---------------|-------------|-----|-----|
| CLCC-20 | SnPb/SnPb | 0 | 0 | 0 |
| | SAC/SAC | + | ++ | ++ |
| | SACB/SACB | ++ | ++ | ++ |
| | SAC/SnPb | 0 | - | 0 |
| | SACB/SnPb | + | + | + |
| TSOP-50 | SnPb/SnPb | 0 | 0 | 0 |
| | SAC/SnCu | + | ++ | ++ |
| | SACB/SnCu | 0 | + | ++ |
| | SAC/SnPb | + | + | + |
| | SACB/SnPb | -- | -- | -- |
| BGA-225 | SnPb/SnPb | 0 | 0 | 0 |
| | SAC/SAC | ++ | ++ | ++ |
| | SACB/SAC | ++ | ++ | ++ |
| | SAC/SnPb | -- | -- | -- |
| | SACB/SnPb | -- | n/a | -- |
| TQFP-144 | SnPb/Sn | 0 | 0 | 0 |
| | SAC/Sn | ++ | ++ | ++ |
| | SACB/Sn | ++ | ++ | ++ |
| TQFP-208 | SnPb/NiPdAu | 0 | 0 | 0 |
| | SAC/NiPdAu | ++ | ++ | ++ |
| | SACB/NiPdAu | ++ | ++ | ++ |



Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
- Combined Environments Testing **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C)  **Rockwell
Collins**
- Vibration Testing   **CELESTICA**
- Mechanical Shock Testing  **BOEING®**



Combined Environments Test

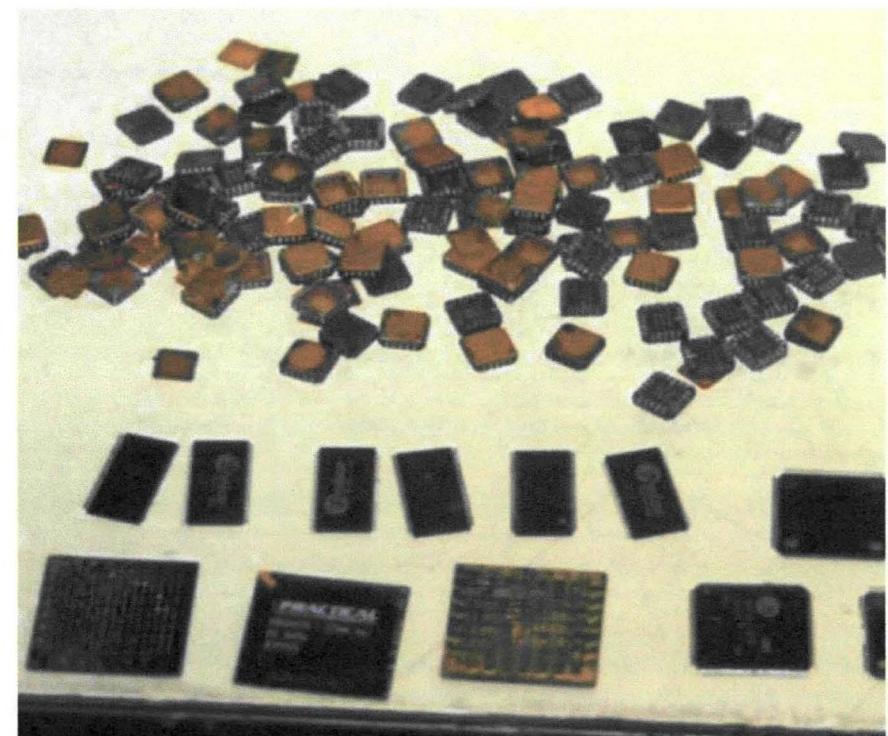
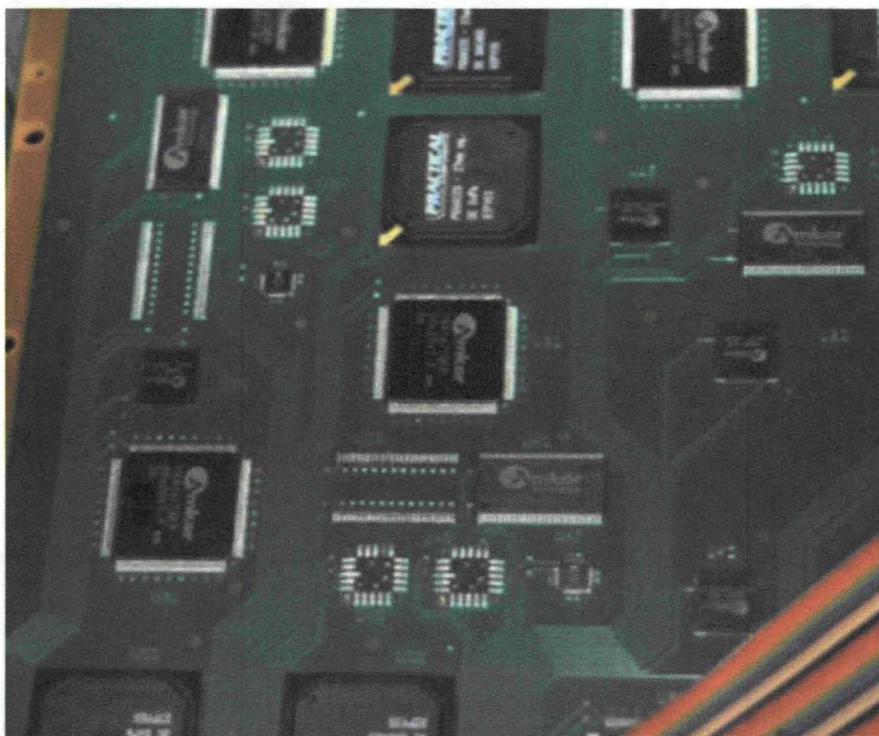
- -55°C to +125°C
- 20°C/minute ramp
- 15 minute dwell at -55°C and +125°C
- Vibration for the duration of the thermal cycle
- 10 g_{rms} pseudo-random vibration initially
- Increase vibration level 5 g_{rms} after every 50 cycles
- 55 g_{rms} maximum





Combined Environments Test

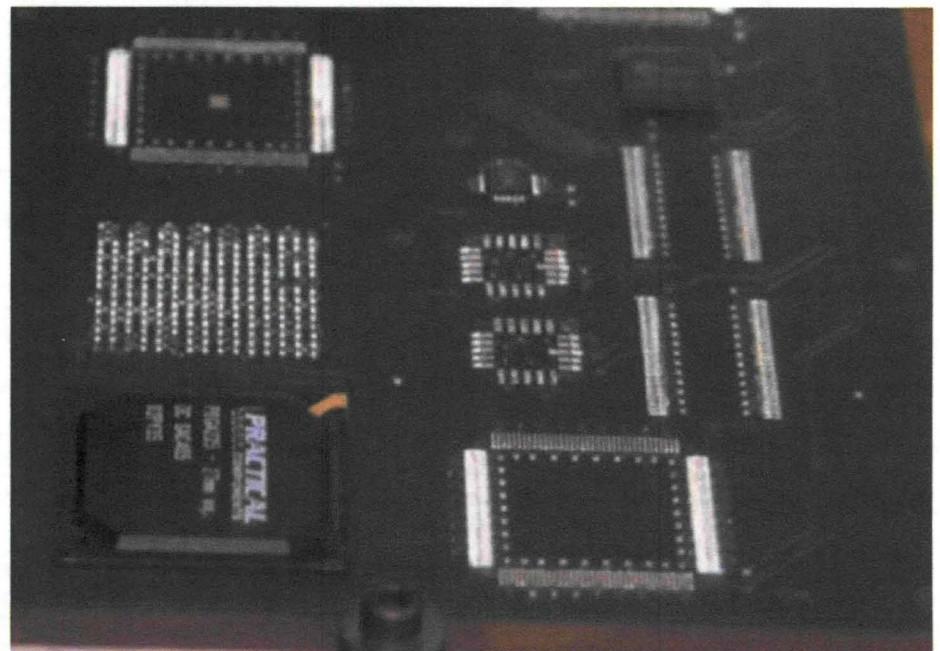
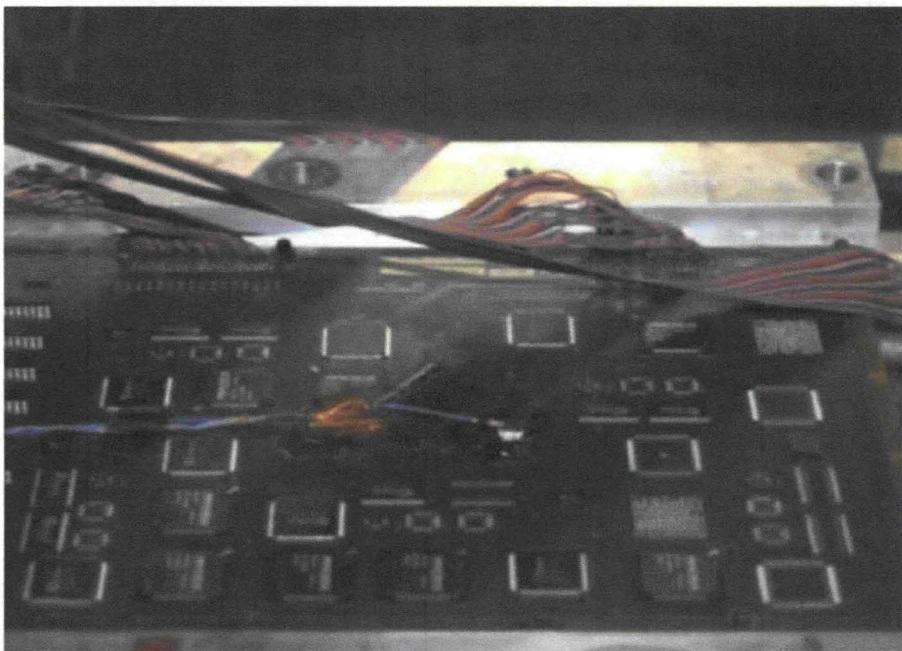
- Overall, the component type had the greatest effect on solder joint reliability performance.
- Of the surface mount technology, the **BGA-225 components performed the worst.**
- The results of the Combined Environment test results suggest **tin-lead finished components soldered with tin-lead solder paste were the most reliable.**





Combined Environments Test

- The test results showed the tin-silver-copper soldered components were less reliable than the tin-lead soldered controls.
- The lower reliability of the tin-silver-copper 305 solder joints does not necessarily rule out the use of tin-silver-copper solder alloy on military electronics. **For several of the investigation DOE combinations**, tin-silver-copper 305 solder performed statistically **as good as** or equal to the baseline, **tin-lead solder**.





Combined Environments Test

Relative Solder Performance, Manufactured Test Vehicles

- Data which is within 5% of the baseline is denoted with a 0.
- Single symbols, – or +, denote data that is 5% to 20% above (+) or below (-) the baseline.
- Double symbols, -- or ++, denote data that is more than 20% above (++) or below (--) the baseline.

- Green cells denote performance better than the SnPb baseline
- Yellow cells denote performance worse than the SnPb baseline.
- Red cells denote data that is grossly worse than the SnPb baseline.

| Board Finish | Component | Alloy | Finish | Nf (1%) | Nf (10%) | Nf (63.2%) |
|--------------|-----------|--------|--------|---------|----------|------------|
| ImAg | BGA-225 | SAC305 | SAC405 | + | 0 | - |
| ImAg | BGA-225 | SN100C | SAC405 | - | - | -- |
| ImAg | BGA-225 | SnPb | SAC405 | -- | -- | -- |
| ImAg | BGA-225 | SAC305 | SnPb | -- | -- | -- |
| ImAg | BGA-225 | SN100C | SnPb | -- | -- | -- |
| ImAg | BGA-225 | SnPb | SnPb | 0 | 0 | 0 |
| ImAg | CLCC-20 | SAC305 | SAC305 | -- | -- | - |
| ImAg | CLCC-20 | SN100C | SAC305 | -- | -- | - |
| ImAg | CLCC-20 | SnPb | SAC305 | -- | -- | - |
| ImAg | CLCC-20 | SAC305 | SnPb | -- | -- | -- |
| ImAg | CLCC-20 | SN100C | SnPb | -- | -- | - |
| ImAg | CLCC-20 | SnPb | SnPb | 0 | 0 | 0 |
| ImAg | CSP-100 | SAC305 | SAC105 | - | 0 | + |
| ImAg | CSP-100 | SN100C | SAC105 | -- | -- | -- |
| ImAg | CSP-100 | SnPb | SAC105 | -- | -- | 0 |
| ImAg | CSP-100 | SAC305 | SnPb | 0 | 0 | 0 |
| ImAg | CSP-100 | SN100C | SnPb | -- | - | + |
| ImAg | CSP-100 | SnPb | SnPb | 0 | 0 | 0 |
| ImAg | TSOP-50 | SAC305 | SnBi | ++ | 0 | -- |
| ImAg | TSOP-50 | SN100C | SnBi | -- | -- | -- |
| ImAg | TSOP-50 | SnPb | SnBi | ++ | + | - |
| ImAg | TSOP-50 | SAC305 | SnPb | 0 | 0 | 0 |
| ImAg | TSOP-50 | SN100C | SnPb | -- | -- | -- |
| ImAg | TSOP-50 | SnPb | SnPb | 0 | 0 | 0 |



Combined Environments Test

Relative Solder Performance, Rework Test Vehicles

- Data which is within 5% of the baseline is denoted with a 0.
- Single symbols, – or +, denote data that is 5% to 20% above (+) or below (-) the baseline.
- Double symbols, -- or ++, denote data that is more than 20% above (++) or below (--) the baseline.
- Green cells denote performance better than the SnPb baseline
- Yellow cells denote performance worse than the SnPb baseline.
- Red cells denote data that is grossly worse than the SnPb baseline.
- Please note, the data for SnPb/SnPb Manufactured test vehicles was used as the baseline for the relative solder performance, rework test vehicles

| TV | Board Finish | Component | Alloy | Finish | New Finish | Rework Solder | Nf (1%) | Nf (10%) | Nf (63.2%) |
|-----|--------------|-----------|--------|--------|------------|---------------|---------|----------|------------|
| RWK | ImAg | BGA-225 | SAC305 | SAC405 | SAC405 | Flux Only | ++ | ++ | - |
| RWK | ImAg | BGA-225 | SAC305 | SAC405 | SAC405 | SnPb | ++ | ++ | - |
| RWK | ImAg | BGA-225 | SAC305 | SnPb | | | ++ | 0 | -- |
| RWK | ImAg | BGA-225 | SnPb | SAC405 | | | ++ | ++ | - |
| RWK | ImAg | BGA-225 | SnPb | SnPb | SAC405 | SnPb | -- | -- | -- |
| RWK | ImAg | BGA-225 | SnPb | SnPb | SnPb | Flux Only | ++ | ++ | -- |
| MFG | ImAg | BGA-225 | SnPb | SnPb | | | 0 | 0 | 0 |
| RWK | ImAg | CLCC-20 | SAC305 | SnPb | | | -- | -- | -- |
| RWK | ImAg | CLCC-20 | SnPb | SAC305 | | | -- | -- | -- |
| MFG | ImAg | CLCC-20 | SnPb | SnPb | | | 0 | 0 | 0 |
| RWK | ImAg | CSP-100 | SAC305 | SAC105 | SAC105 | Flux Only | -- | - | ++ |
| RWK | ImAg | CSP-100 | SAC305 | SAC105 | SAC105 | SnPb | -- | -- | -- |
| RWK | ImAg | CSP-100 | SAC305 | SAC105 | | | -- | - | 0 |
| RWK | ImAg | CSP-100 | SAC305 | SnPb | | | | | |
| RWK | ImAg | CSP-100 | SnPb | SAC105 | | | -- | -- | -- |
| RWK | ImAg | CSP-100 | SnPb | SnPb | SAC105 | SnPb | | | |
| RWK | ImAg | CSP-100 | SnPb | SnPb | SnPb | Flux Only | | | |
| MFG | ImAg | CSP-100 | SnPb | SnPb | | | 0 | 0 | 0 |
| RWK | ImAg | TSOP-50 | SAC305 | Sn | Sn | SnPb | ++ | + | - |
| RWK | ImAg | TSOP-50 | SAC305 | SnBi | SnBi | SAC305 | ++ | + | -- |
| RWK | ImAg | TSOP-50 | SAC305 | SnBi | | | ++ | ++ | - |
| RWK | ImAg | TSOP-50 | SAC305 | SnPb | | | ++ | ++ | ++ |
| RWK | ImAg | TSOP-50 | SnPb | Sn | | | ++ | ++ | - |
| RWK | ImAg | TSOP-50 | SnPb | SnBi | | | ++ | ++ | 0 |
| RWK | ImAg | TSOP-50 | SnPb | SnPb | Sn | SnPb | ++ | ++ | - |
| RWK | ImAg | TSOP-50 | SnPb | SnPb | SnPb | SnPb | + | 0 | - |
| MFG | ImAg | TSOP-50 | SnPb | SnPb | | | 0 | 0 | 0 |



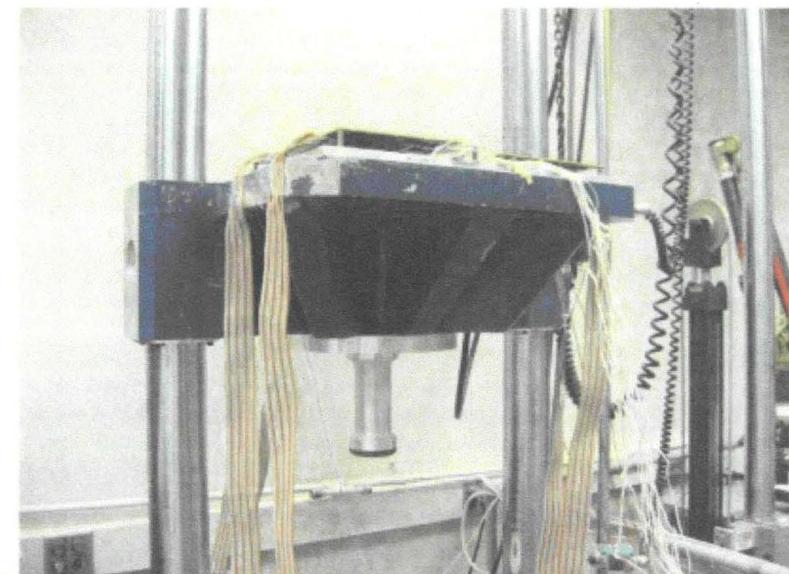
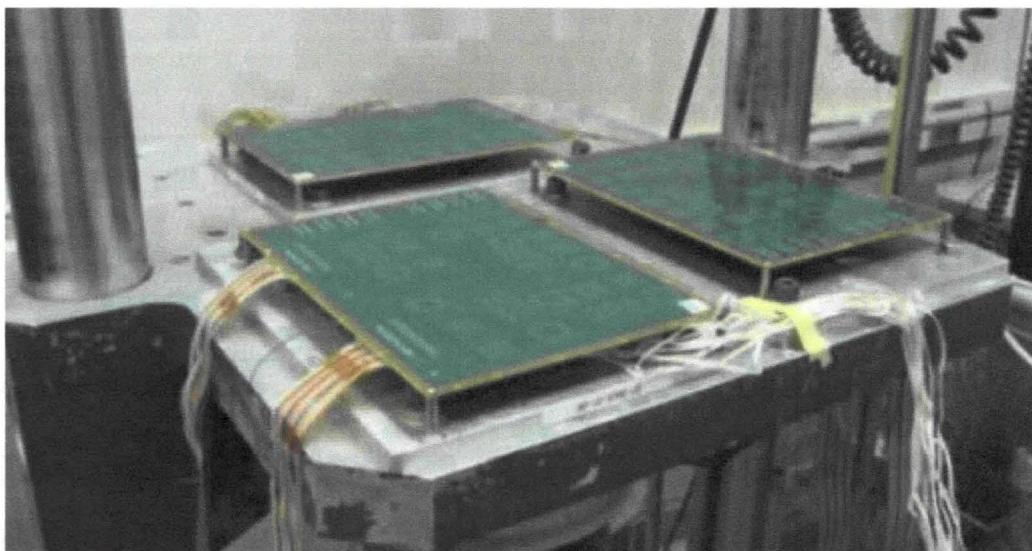
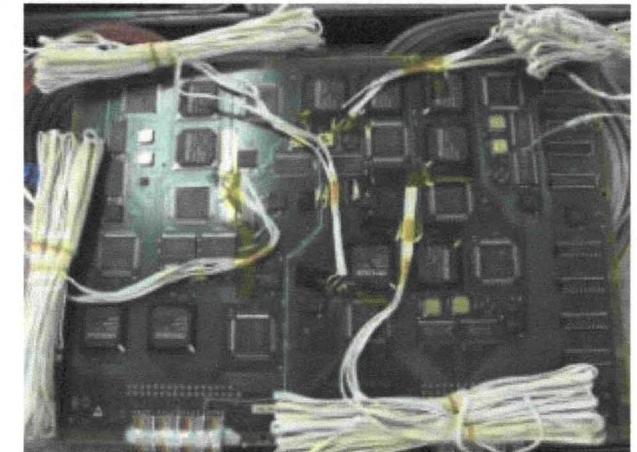
Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
- Combined Environments Testing **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C)  **Rockwell Collins**
- Vibration Testing  **BOEING®**  **CELESTICA**
- Mechanical Shock Testing  **BOEING®**

Drop Testing - NSWC Crane Test Vehicles



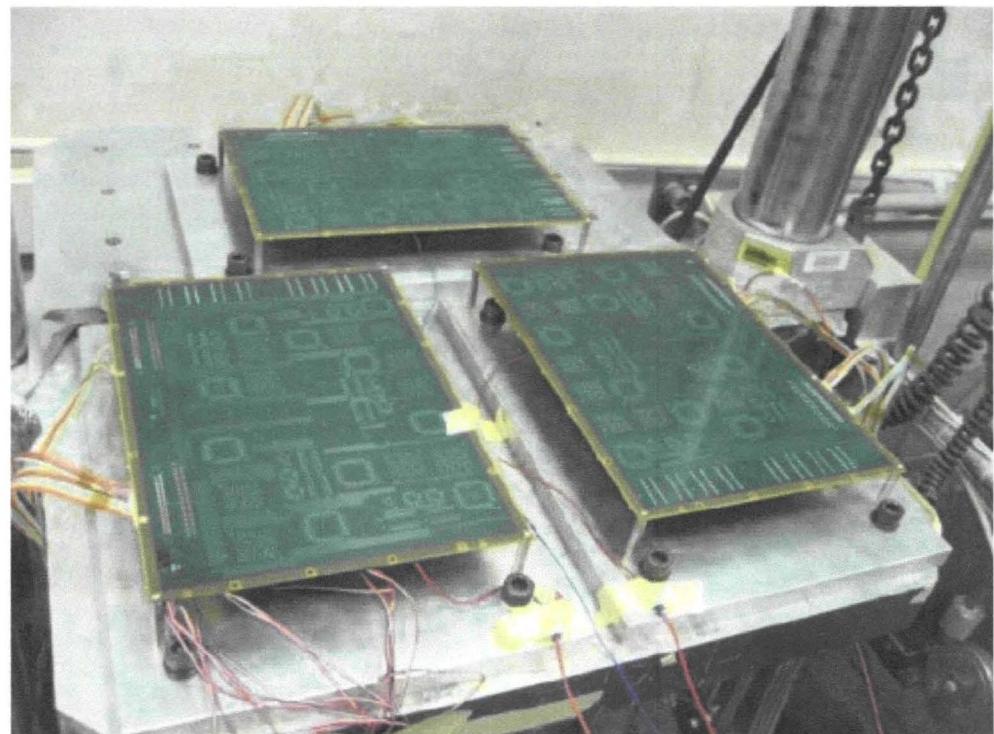
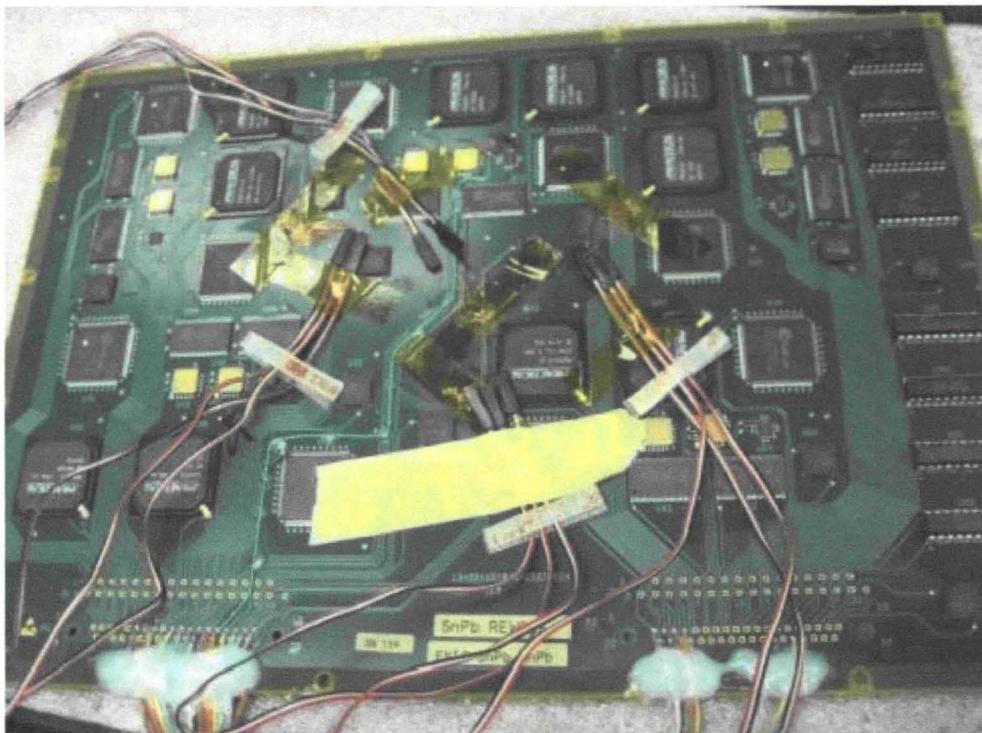
- Shock parameters: 500 G, 2.0 ms duration (340 G for cards 80, 82, 87 for first 10 drops)
- Number of drops: 20
- 9 cards in total / 3 cards tested per drop
- Each card monitored for shock response
- Each card monitored for resistance
- Cards 80, 83, 86 monitored for strain



Drop Testing - NASA-DoD Test Vehicles



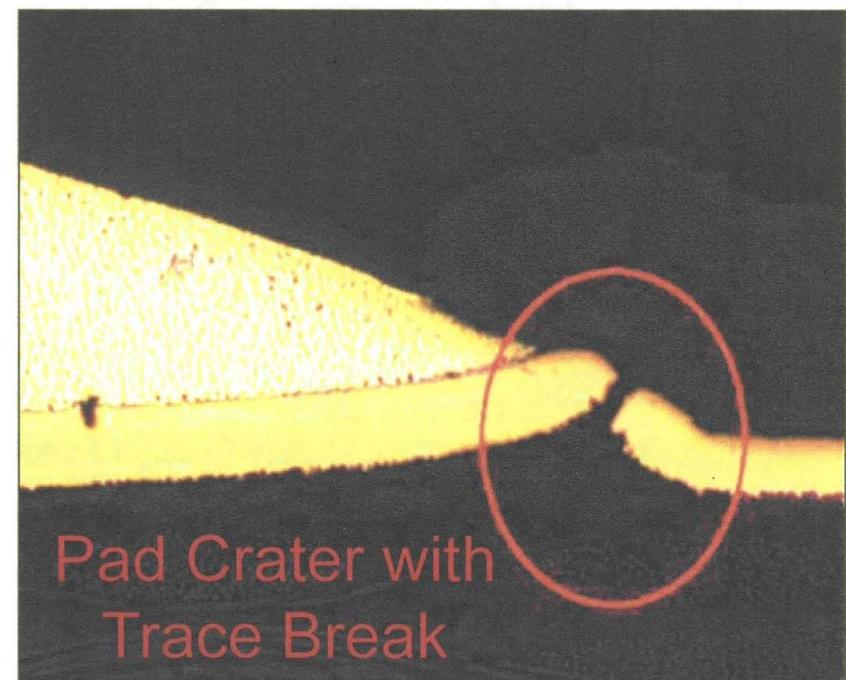
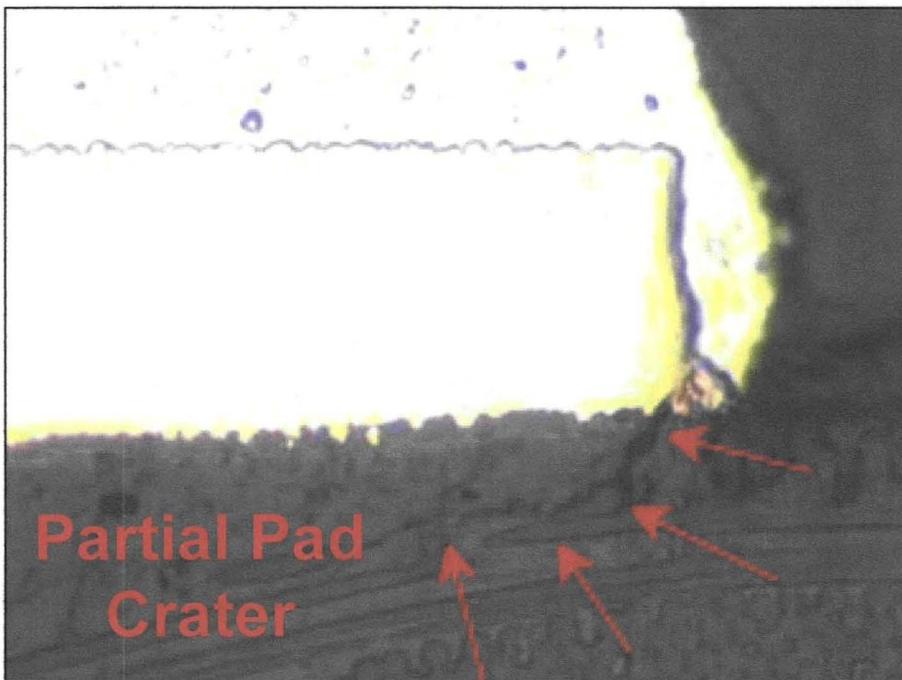
- Shock testing will be conducted in the Z - axis
- 500Gpk input, 2ms pulse duration
- Test vehicles will be dropped until all monitored components fail or 10 drops have been completed





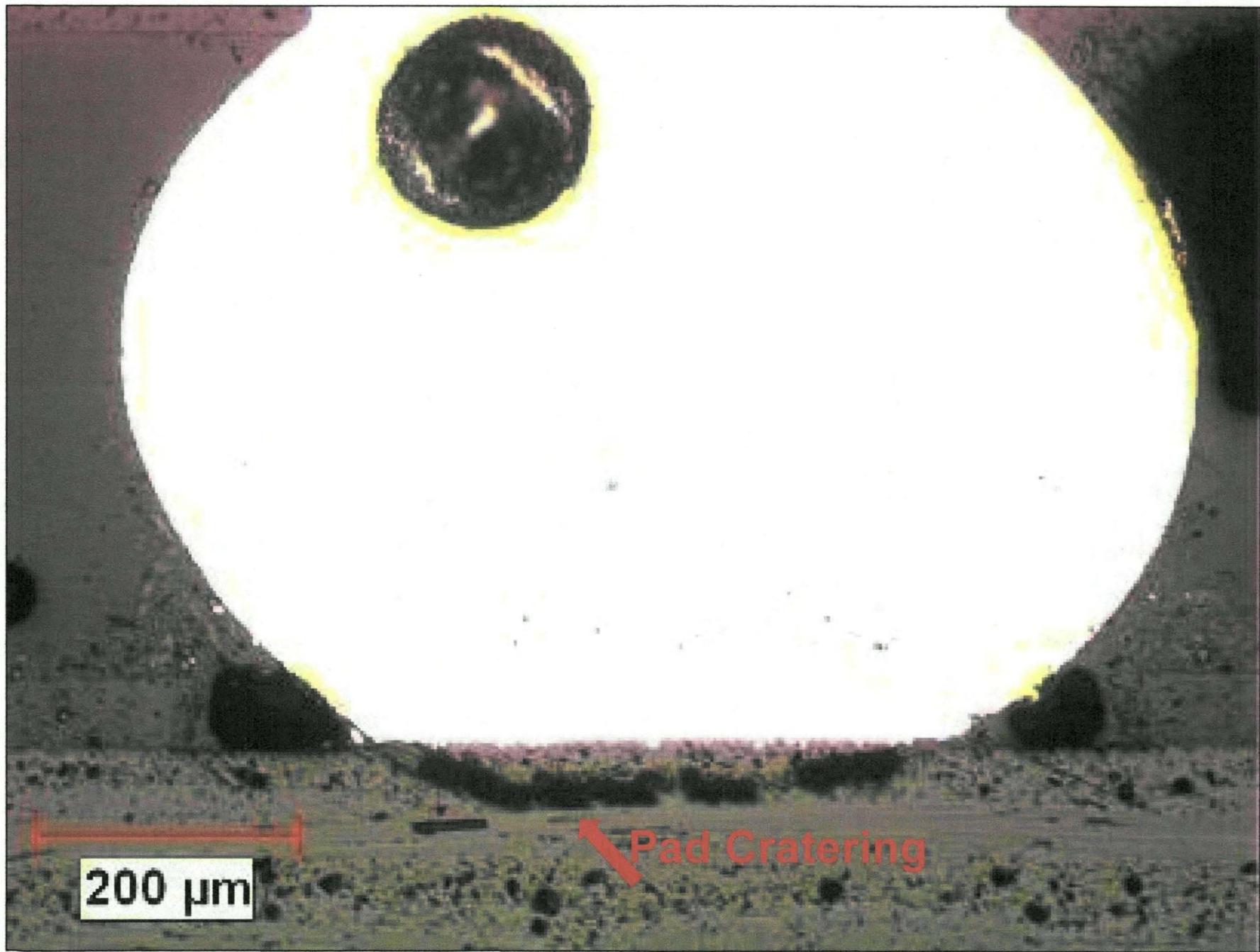
Drop Testing

- Drop test reliability was **component type dependent**.
- The only component type to show a significant number of electrical failures during this test were the **BGAs**. The BGA-225 electrical failures mostly occurred at or near the corner joints.
- The predominant damage mechanism in drop testing is **pad cratering**. Cracks propagate through the board material between the laminate and glass fiber under the pads.





Drop Testing





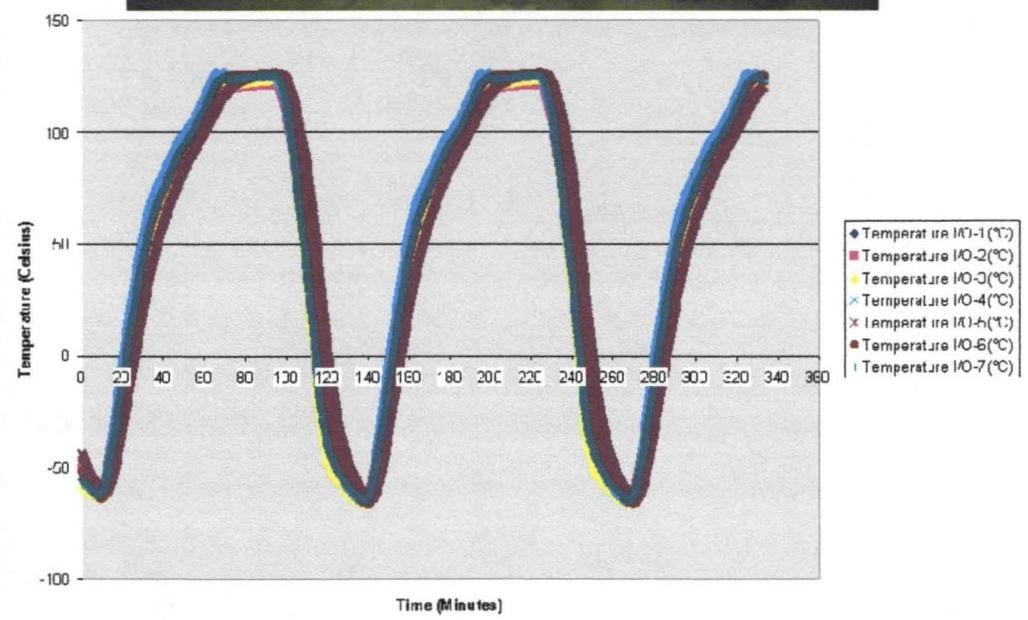
Testing

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- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C)  **Rockwell
Collins**
- Vibration Testing   **CELESTICA**
- Mechanical Shock Testing 



Thermal Cycle Testing (-55/+125°C)

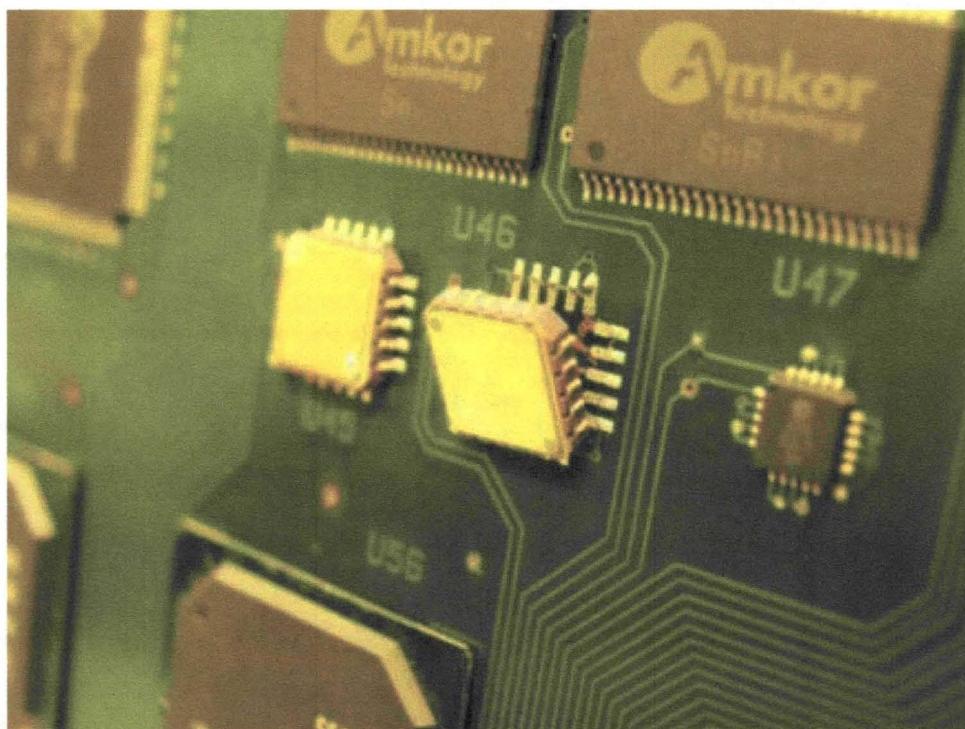
- 5 to 10°C/minute ramp
- 30 minute dwell at 125°C
- 10 minute dwell at -55°C
- Completed 4,068 thermal cycles





Thermal Cycle Testing (-55/+125°C)

- Completed 4,068 thermal cycles
 - Initial Analysis = In general, the preliminary results show that the **SnPb** solder alloy **out performed** the two **lead-free** solder alloys in many cases.
 - However, the performance of the lead-free solder alloys was not without merit. The question to be answered is: "**How good is good enough** for a product application?"





Thermal Cycle Testing (-55/+125°C)

Manufactured Test Vehicles – Failure Rates

| Component Type | Total Failures | Population | Percent Failed |
|----------------|----------------|------------|----------------|
| CLCC-20 | 309 | 311 | 99% |
| QFN-20 | 88 | 134 | 66% |
| QFP-144 | 306 | 309 | 99% |
| PBGA-225 | 253 | 279 | 91% |
| PDIP-20 | 189 | 220 | 86% |
| CSP-100 | 252 | 281 | 90% |
| TSOP-50 | 249 | 249 | 100% |

Rework Test Vehicles – Failure Rates

| Component Type | Total Failures | Population | Percent Failed |
|----------------|----------------|------------|----------------|
| PBGA-225 | 51 | 66 | 77% |
| PDIP-20 | 57 | 60 | 95% |
| CSP-100 | 45 | 67 | 67% |
| TSOP-50 | 99 | 99 | 100% |



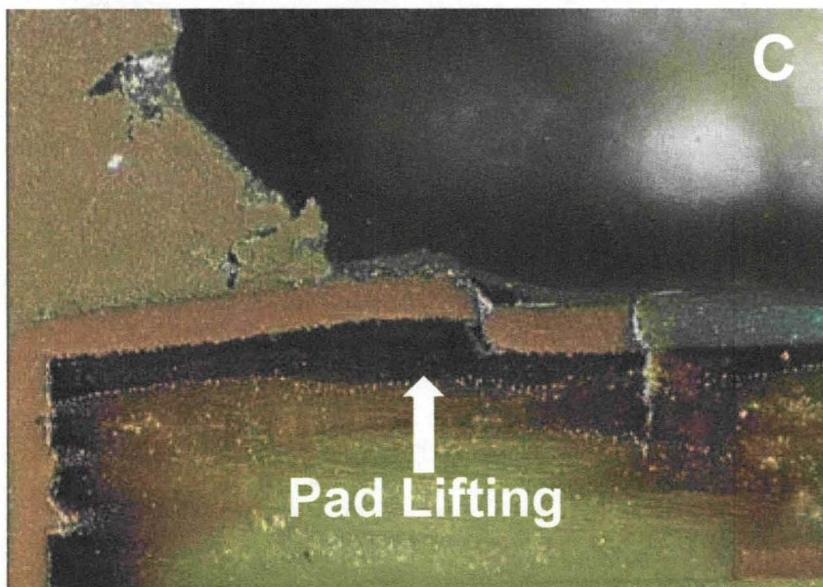
Three sufficient conditions resulting in unexpectedly high PDIP failures {cracked traces} on lead-free assemblies: **A+B+C = Failure**



Etch defect where the trace goes into the pad {attributed to the silver plating process}



Copper erosion caused by lead-free solder



Pad Lifting



Cracked trace



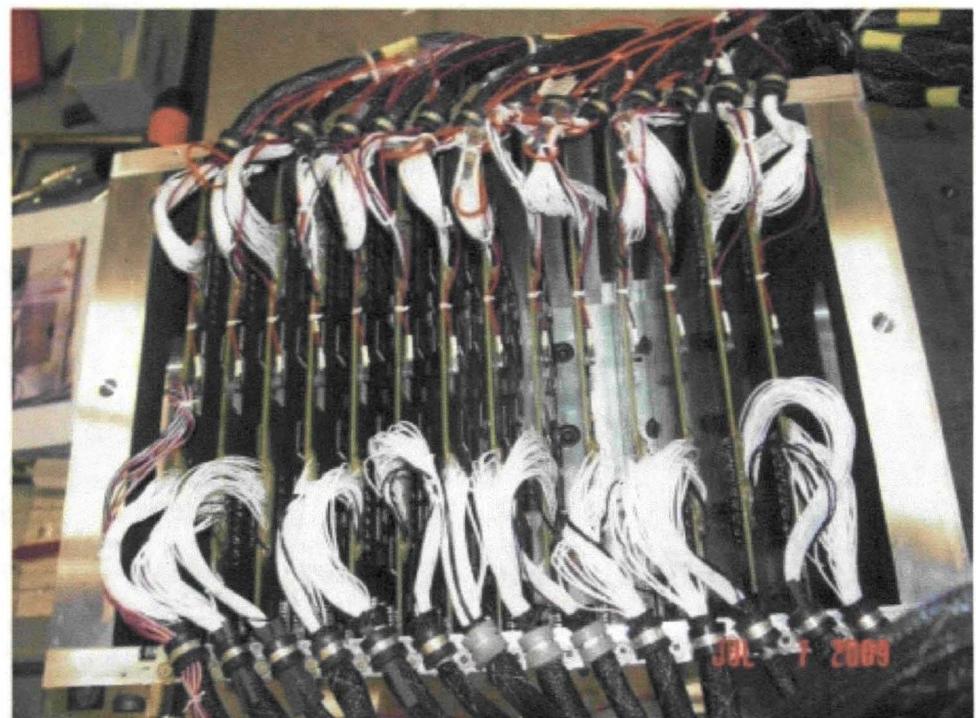
Testing

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Collins**
- Vibration Testing   **BOEING®** **CELESTICA**
- Mechanical Shock Testing  **BOEING®**



Vibration Testing

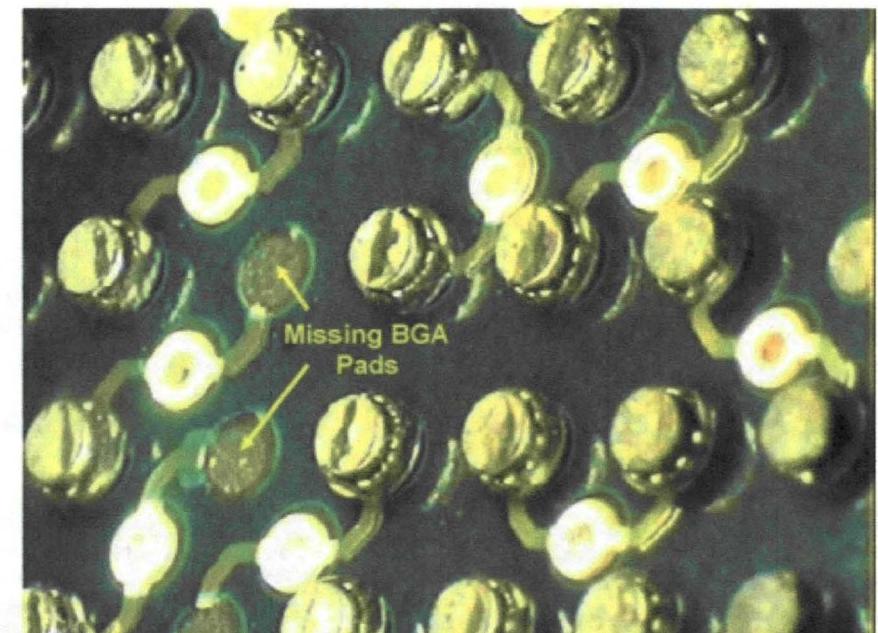
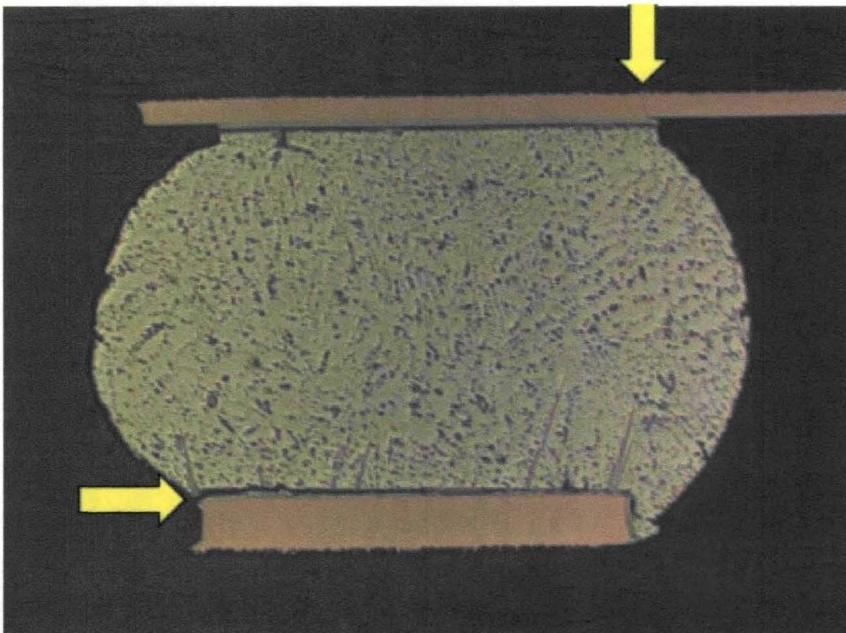
- Subject the test vehicles to 8.0 g_{rms} for one hour.
- Then increase the Z-axis vibration level in 2.0 g_{rms} increments, shaking for one hour per step until the 20.0 g_{rms} level is completed.
- Then subject the test vehicles to a final one hour of vibration at 28.0 g_{rms}.





Vibration Testing

- The results of this study suggest that for many component types, the **lead-free solders tested are not as reliable as eutectic SnPb solder** with respect to vibration. **Rework** also had a **negative effect** on both SnPb and lead-free solders with respect to vibration.
- For severe vibration environments, the use of lead-free solders may require the use of stiffeners, bumpers, or vibration isolators to reduce PWA flexure and reduce solder joint strains to acceptable levels.





Vibration Testing

Percentage of Components Failed (Includes Mixed Solders)
NASA-DoD Test Vehicles Only

| Component | % of Components Failed During Vibration Testing | | | | |
|-----------|---|--------------|--------------|------------------------|---------------|
| | "Manufactured" Test Vehicles | | | "Rework" Test Vehicles | |
| | SnPb Paste | SAC305 Paste | SN100C Paste | SnPb Paste | Pb-Free Paste |
| BGA-225 | 84 | 98 | 100 | 100 | 100 |
| CLCC-20 | 32 | 43 | 90 | 35 | 68 |
| CSP-100 | 62 | 73 | 70 | 62 | 80 |
| PDIP-20 | 98 | 92 | 100 | 88 | 96 |
| QFN-20 | 0 | 21 | 20 | 8 | 10 |
| TQFP-144 | 60 | 63 | 64 | 70 | 70 |
| TSOP-50 | 62 | 73 | 86 | 77 | 80 |



Vibration Testing

Ranking of Solder Alloy/Component Finish Combinations NASA-DoD Test Vehicles Only

| | | Relative Ranking (Solder Alloy / Component Finish) | | | | | | | | |
|----------|-------------------|--|-------------------|-------------------|--------------------------|--------------------------|-------------------------------------|--|------------------------------------|---------------------|
| BGA-225 | Sn37Pb/ Sn37Pb | SAC305/ SAC405 | Sn37Pb/ SAC405 | SAC305/ Sn37Pb | Rwk Flux Only/ Sn37Pb | Rwk Flux Only/ SAC405 | Rwk Sn37Pb/SAC405 (SnPb Profile) | Rwk Sn37Pb/SAC405 (Pb-Free Profile) | SN100C/ SAC405 | |
| | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| CLCC-20 | Sn37Pb/ Sn37Pb | SAC305/ SAC305 | Sn37Pb/ SAC305 | SAC305/ Sn37Pb | SN100C/ SAC305 | | 1 | 1 | 2 | 3 |
| | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| CSP-100 | Sn37Pb/ Sn37Pb | SAC305/ SAC105 | Sn37Pb/ SAC105 | SAC305/ Sn37Pb | Rwk Flux Only/ Sn37Pb | Rwk Flux Only/ SAC105 | Rwk Sn37Pb/SAC105 (SnPb Profile) | Rwk Sn37Pb/SAC105 (Pb-Free Profile) | SN100C/ SAC105 | |
| | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 3 | 3 | 1 |
| PDIP-20 | Sn37Pb/ SnPb | SN100C/ Sn | Sn37Pb/ NiPdAu | Rwk Sn37Pb/ Sn | Rwk Sn100C/ Sn | SN100C/ NiPdAu | | 1 | 3 | 3 |
| | 1 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| QFN-20 | Sn37Pb/ Sn37Pb | SAC305/ Sn | Sn37Pb/ Sn | SAC305/ Sn37Pb | SN100C/ Sn | | 1 | 2 | 1 | 1 |
| | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 |
| TQFP-144 | Sn37Pb/ Sn | SAC305/ Sn | Sn37Pb/ NiPdAu | SAC305/ NiPdAu | Sn37Pb/ Sn37Pb Dip | SAC305/ SAC305 Dip | SN100C/ Sn | | 1 | 1 |
| | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 |
| TSOP-50 | Sn37Pb/ SnPb | Sn37Pb/ Sn | Sn37Pb/ SnBi | SAC305/ Sn | SAC305/ SnBi | SAC305/ SnPb | Rwk Sn37Pb/ SnPb | Rwk Sn37Pb/Sn (SnPb Profile) | Rwk Sn37Pb/Sn (Pb-free Profile) | Rwk SAC305/ SnBi |
| | 1 | 2* | 2* | 2* | 2* | 2 | 2 | 2* | 2* | 2 |

*Performance relative to Sn37Pb control may depend on orientation of the TSOP

1 = as good as or better than Sn37Pb control

2 = worse than Sn37Pb control

3 = much worse than Sn37Pb control



Testing

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- Combined Environments Testing  **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C)  **Rockwell
Collins**
- Vibration Testing  **BOEING®**  **CELESTICA**
- Mechanical Shock Testing  **BOEING®**



Mechanical Shock Testing

- Level 1: 100 shock pulses using a 20 G SRS
 - Functional Test for Flight Equipment; MIL-STD-810G, Method 516.6
- Level 2: 100 shock pulses using a 40 G SRS
 - Functional Test for Ground Equipment; MIL-STD-810G, Method 516.6
- Level 3: 100 shock pulses using a 75 G SRS
 - Crash Hazard Test for Ground Equipment; MILSTD-810G, Method 516.6
- Level 4: 100 shock pulses using a 100 G SRS
- Level 5: 100 shock pulses using a 200 G SRS
- Level 6: 400 shock pulses using a 300 G SRS



Mechanical Shock Testing

- In general, the **pure lead-free systems** (SAC305/SAC405 balls, SAC305/SAC105 balls, SAC305/Sn, and SN100C/Sn) **performed as well or better than the SnPb controls** (SnPb/SnPb or SnPb/Sn).
- Many of the **BGA failures** (SnPb/SbPb balls, SAC305/SAC405 balls, and mixed technologies) were due to **pad cratering**. This suggests that **lead-free laminates** may be the **weakest link** for large area array components.
- It should be noted that all of the surface mount components **survived** 100 shock pulses at each of the first three test levels {per *MIL-STD-810G, Method 516.6*}. This means that they effectively **passed**:
 - Functional Test for Flight Equipment **33 times**
 - Functional Test for Ground Equipment **33 times**
 - Crash Hazard Test for Ground Equipment **33 times**



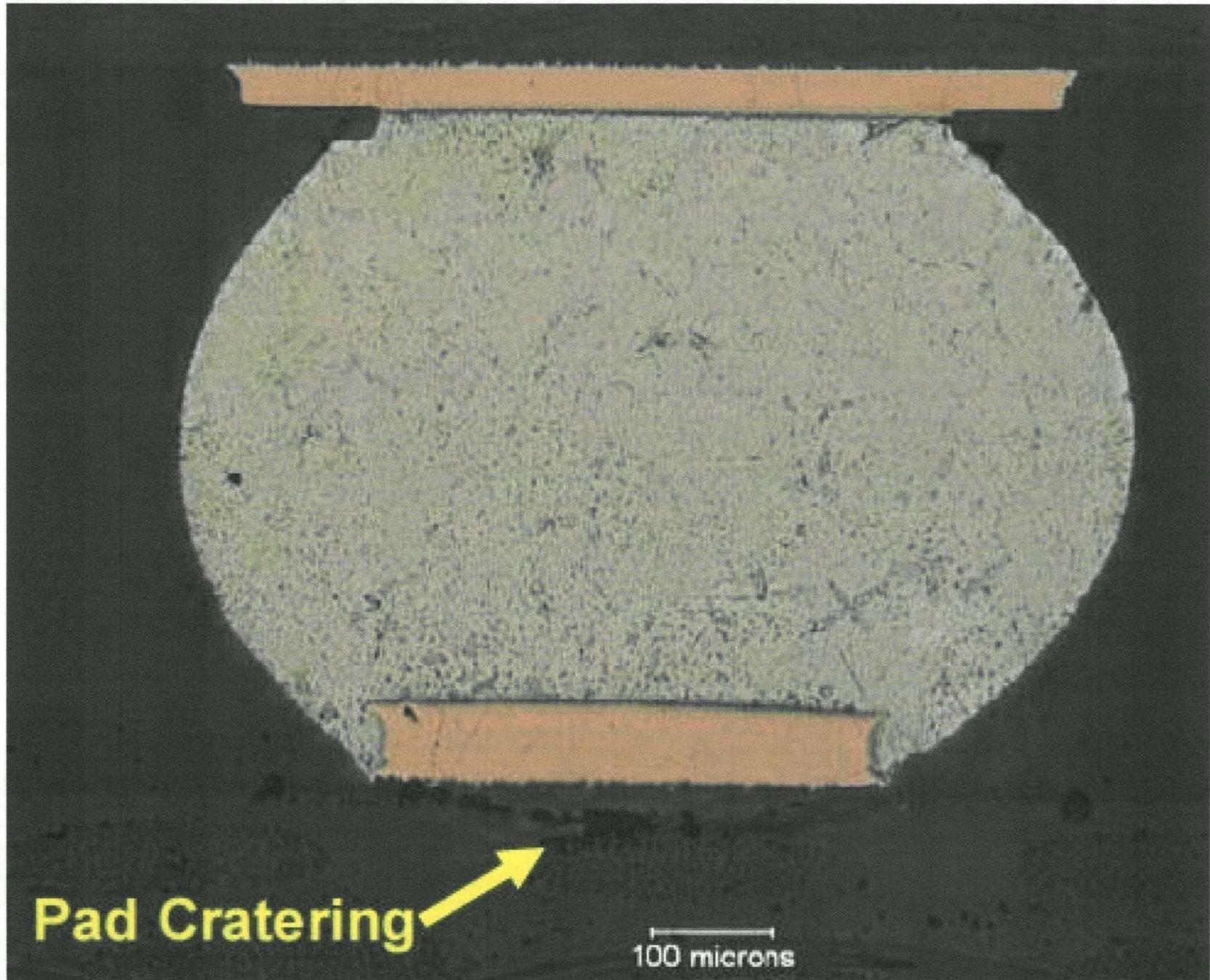
Mechanical Shock Testing

Relative Ranking (Solder/Component Finish)

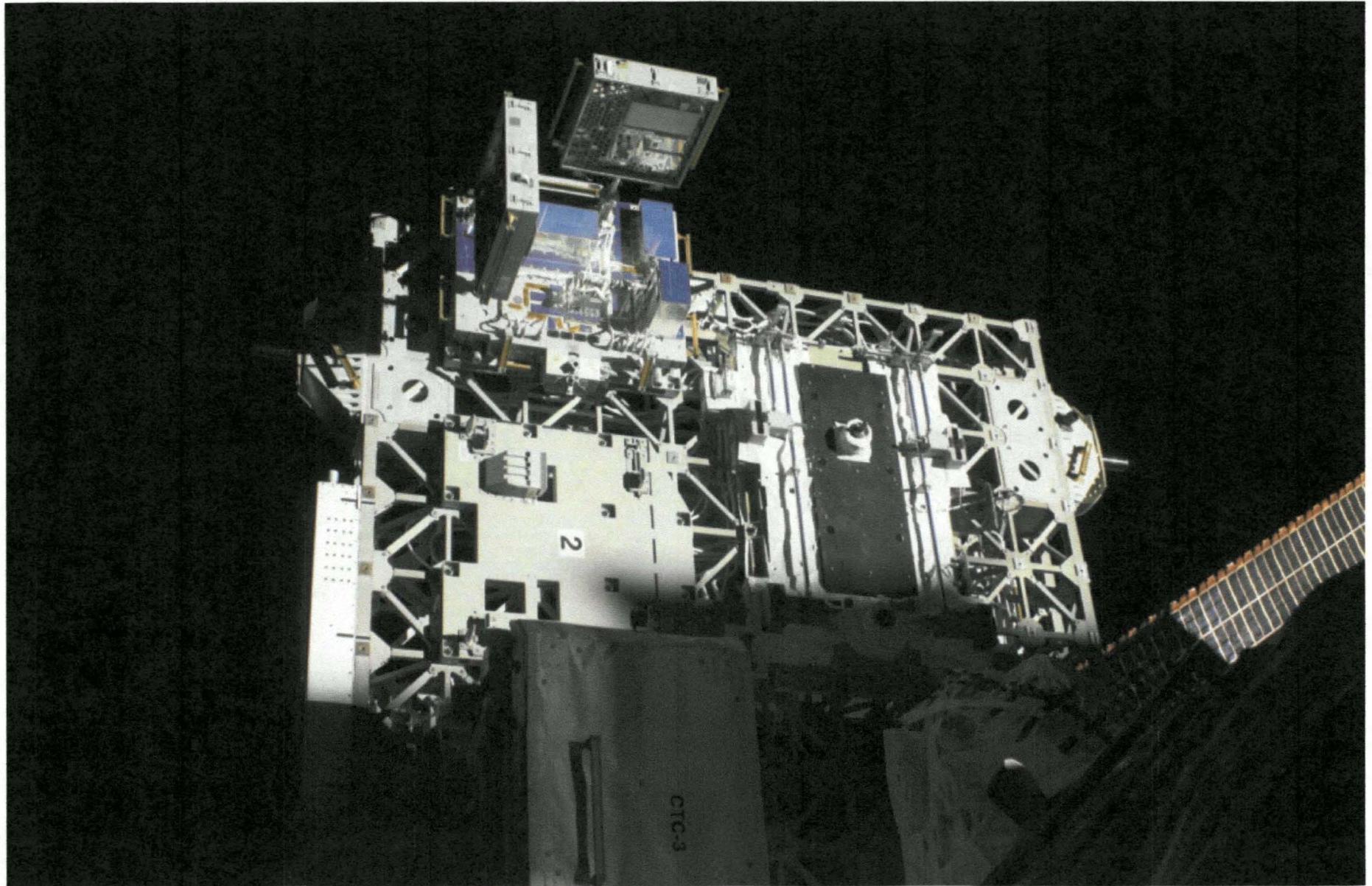
| Component | Sn37Pb/Sn37Pb | SAC305/SAC405 | Sn37Pb/SAC405 | SAC305/Sn37Pb | Rwk Flux Only /Sn37Pb | Rwk Flux Only /SAC405 | Rwk Sn37Pb/SAC405 (SnPb Profile) | Rwk Sn37Pb/SAC405 (Pb-Free Profile) | |
|-----------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|--|---|---------------------------------------|
| BGA-225 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | |
| Component | Sn37Pb/Sn37Pb | SAC305/SAC305 | Sn37Pb/SAC305 | SAC305/Sn37Pb | | | | | |
| CLCC-20 | 1 | 2 | 2 | 2 | | | | | |
| Component | Sn37Pb/Sn37Pb | SAC305/SAC105 | Sn37Pb/SAC105 | SAC305/Sn37Pb | Rwk Flux Only /Sn37Pb | Rwk Flux Only /SAC105 | Rwk Sn37Pb/SAC105 (SnPb Profile) | Rwk Sn37Pb/SAC105 (Pb-Free Profile) | |
| CSP-100 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | |
| Component | Sn37Pb/SnPb | SN100C/Sn | Sn37Pb/NiPdAu | Rwk Sn37Pb/Sn | Rwk SN100C/Sn | | | | |
| PDIP-20 | 1 | 1 | 1 | 2 | 2 | | | | |
| Component | Sn37Pb/Sn37Pb | SAC305/Sn | Sn37Pb/Sn | SAC305/Sn37Pb | | | | | |
| QFN-20 | Not enough failures to rank | | | | | |
| Component | Sn37Pb/Sn | SAC305/Sn | Sn37Pb/NiPdAu | SAC305/NiPdAu | Sn37Pb /Sn37Pb Dip | SAC305 /SAC305 Dip | | | |
| TQFP-144 | 1 | 1 | 1 | 1 | 1 | 2 | | | |
| Component | Sn37Pb/SnPb | Sn37Pb/Sn | Sn37Pb/SnBi | SAC305/Sn | SAC305/SnBi | SAC305/SnPb | Rwk Sn37Pb/SnPb | Rwk Sn37Pb/Sn (SnPb Profile) | Rwk Sn37Pb/Sn (Pb-Free Profile) |
| TSOP-50 | Not enough failures to rank | 2 | 2 | 2 |
| | | | | | | | | | 2 |



Mechanical Shock Testing



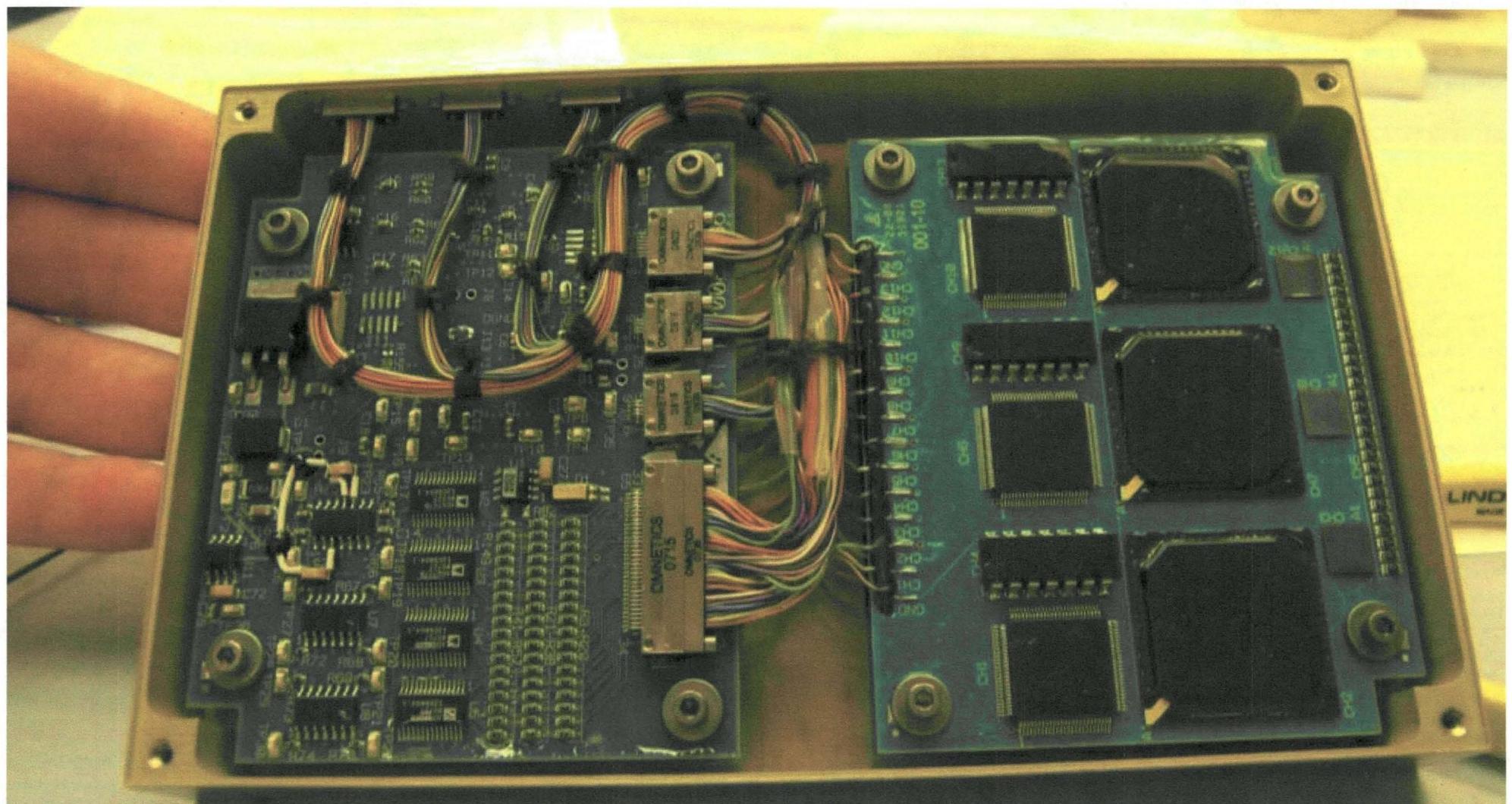
Lead-free Technology Experiment in Space Environment (LTESE)



Lead-free Technology Experiment in Space Environment (LTESE)



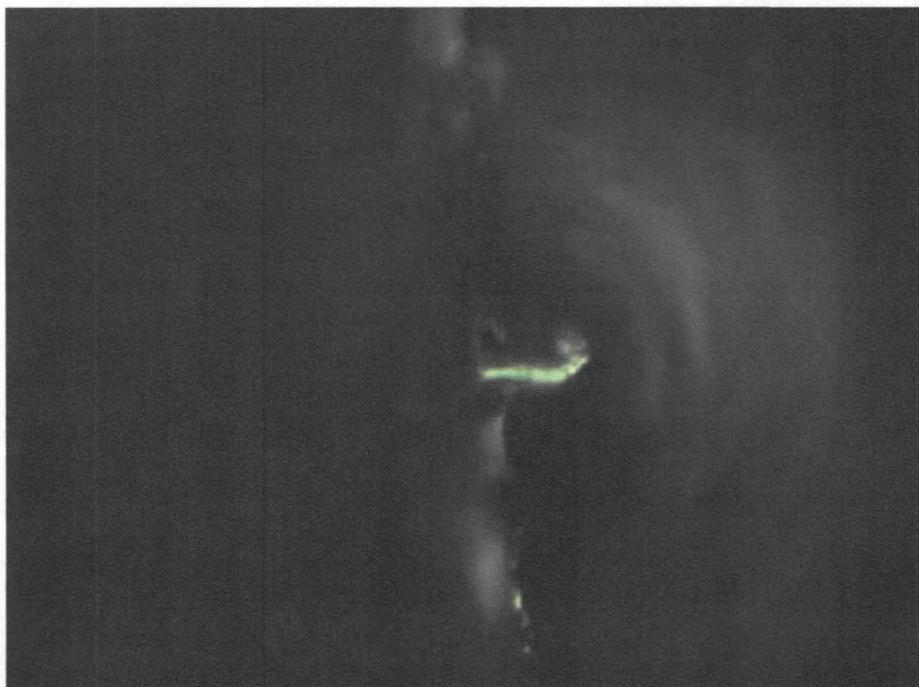
- LTESE operated for about 17 months on the International Space Station



Lead-free Technology Experiment in Space Environment (LTESE)



- For the LF boards, there may be signs of tin whisker growth on the PDIPs {@ 1000X}
- For the mixed solder boards, some tin whiskers have been observed on the PDIPs {@ 1000X}
 - ❑ The cards are conformal coated
 - ❑ The whiskers do not exit the coating
 - ❑ These are on the knees of PDIPs on the flight mixed solder board {SnPb board with Pb-free parts using SnPb solder}.
 - ❑ The whisker on the CH4-Lead 6 is 18 µm long.

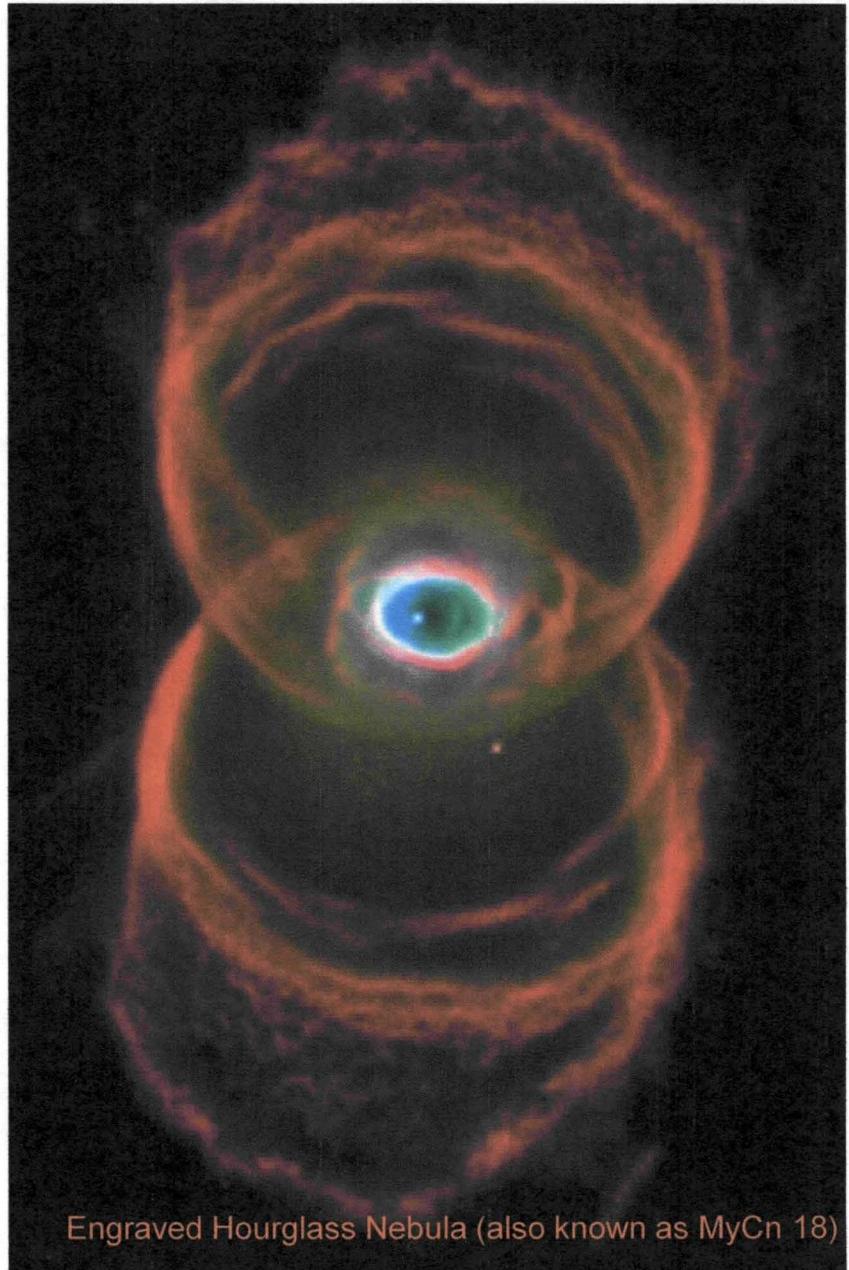




Looking Forward

What's Next?

- How do we build off of the successes of our project
- What critical gaps remain
 - ❑ System-level demonstration/validation of promising Pb-free solders on functional Class 3 aerospace and defense electronic systems. This will also help validate entire Pb-free assemblies in an operational environment.
 - ❑ Reliability data from electronic assemblies designed for operation in harsh aerospace environments {Lead-free Technology Experiment in a Space Environment (LTESE)}
 - ❑ Determine if Pb-free technology effects the functionality of electronic assemblies
- Funding ?



Engraved Hourglass Nebula (also known as MyCn 18)



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